Welcome to aquaCORPS Digital

In January 1990, I launched the first edition of aquaCORPS magazine because I was hungry for information about a new kind of diving that was emerging from the closet, and no one was talking—there was little or no information. Indeed, deep diving, by which I mean diving beyond 40m/130 ft, and its companion decompression diving—the “D-Words”—were strictly verboten among the recreational diving establishment; few could even spell N-I-T-R-O-X, or trimix, let alone knew what they were.

Within two years I coined the moniker “technical diving,” to distinguish this type of diving from recreational diving, and the name stuck, as technical diving began to gain momentum and spread around the globe. In parallel, the magazine, which we subsequently dubbed aquaCORPS: The Journal for Technical Diving, continued to grow in size and readership.

Each issue of aquaCORPS focused on a single topic such mixed gas technology, rebreathers, decompression illness, computing and more. WIRED magazine described it as, “The Sea Geek’s Bible; Part wish list, part chemistry book, part looking glass.” In addition, we launched aquaCORPS’ sister publication, which was more of a newsletter, titled: technicalDIVER.

In 1996, after growing rapidly and moving to newsstand distribution, I ran out of money and was forced to close the company. By that time, we had produced a total of 12 themed issues of aquaCORPS and three issues of technicalDIVER, along with producing the Enriched Air Nitrox Workshop (1992), four annual tek.Conferences (1993-1996), the first EUROTek and ASIATek conferences (1995), and Rebreather Forum 1 & 2 (1994, 1996).

Now more than 30 years since we launched aquaCORPS, I have begun to release sponsored, digital copies of the original magazine including the aquaCORPS MIX issue, BENT issue and this issue of aquaCORPS C2 (rebreather). Note that the text is completely searchable.

I want to thank my illustrious, forward-thinking sponsors, all of which are pioneers in their own right, for making this possible. You will find their content inside the front cover and center spread, in what is otherwise the original magazine. Over the next few years, I plan to progressively release digital versions of all of the back issues of aquaCORPS/technicalDIVER. These will be distributed by our sponsors and a copy will reside at www.aquaCORPS.online.

Thank you for your interest!
Michael Menduno/M2

THE JOURNAL FOR TECHNICAL DIVING

aquaCorps®

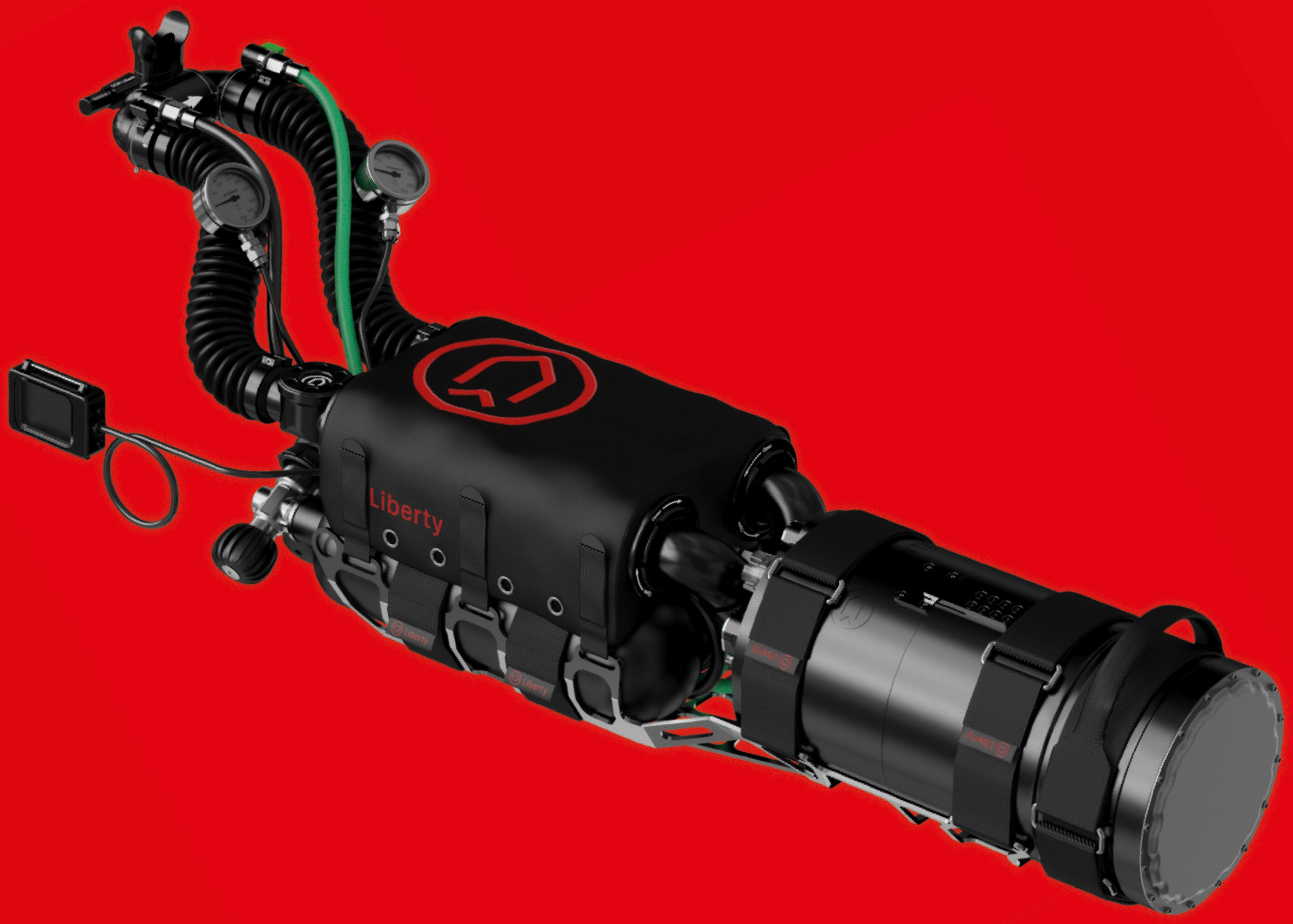
N7

C2

“Like so many devices which at the time of their invention were considered too revolutionary...”

The Electrolung Story
Rebreather Primer
Stoned
O_2 Exposure Mgmt

LIBERTY SIDEMOUNT



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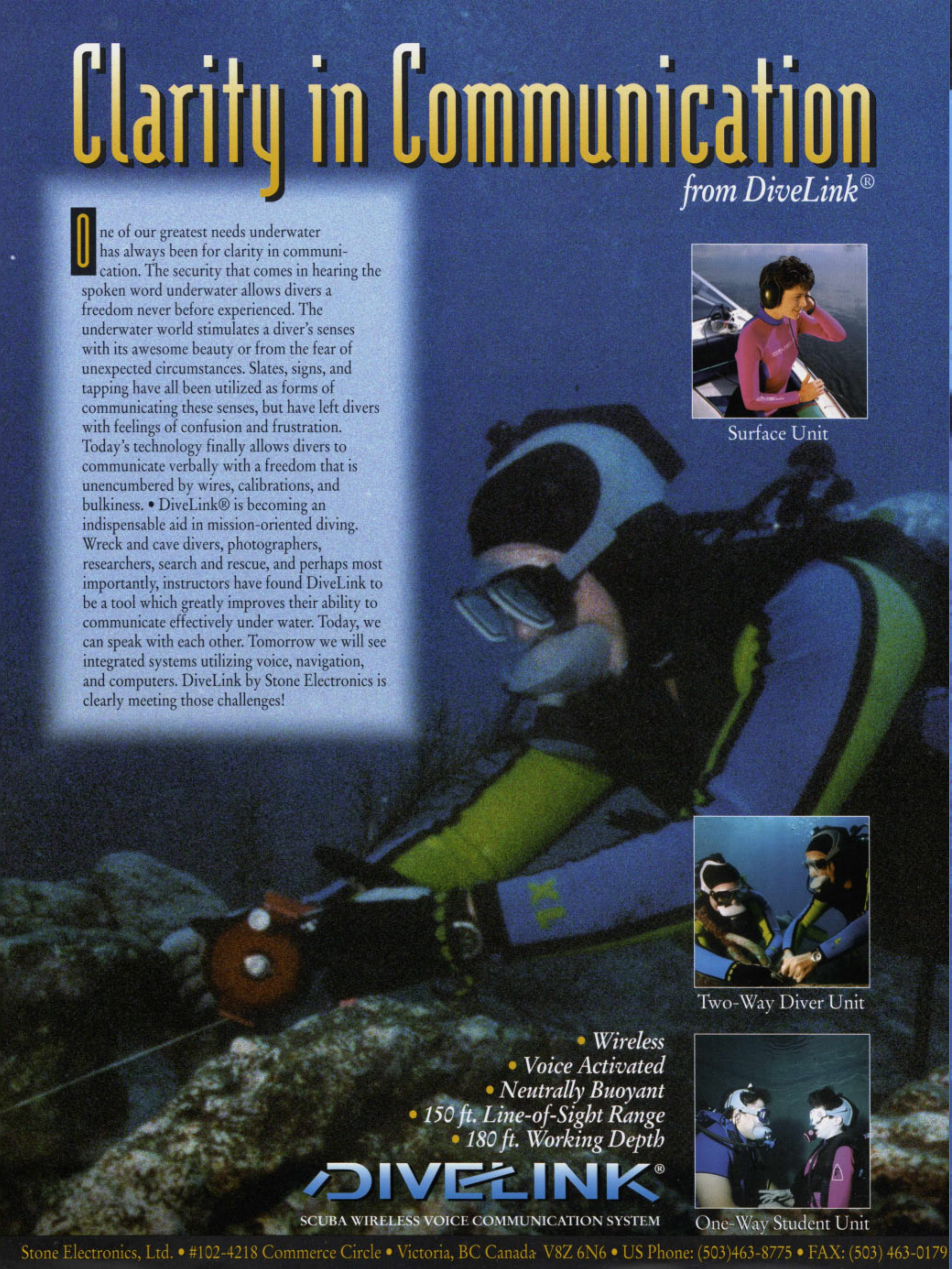

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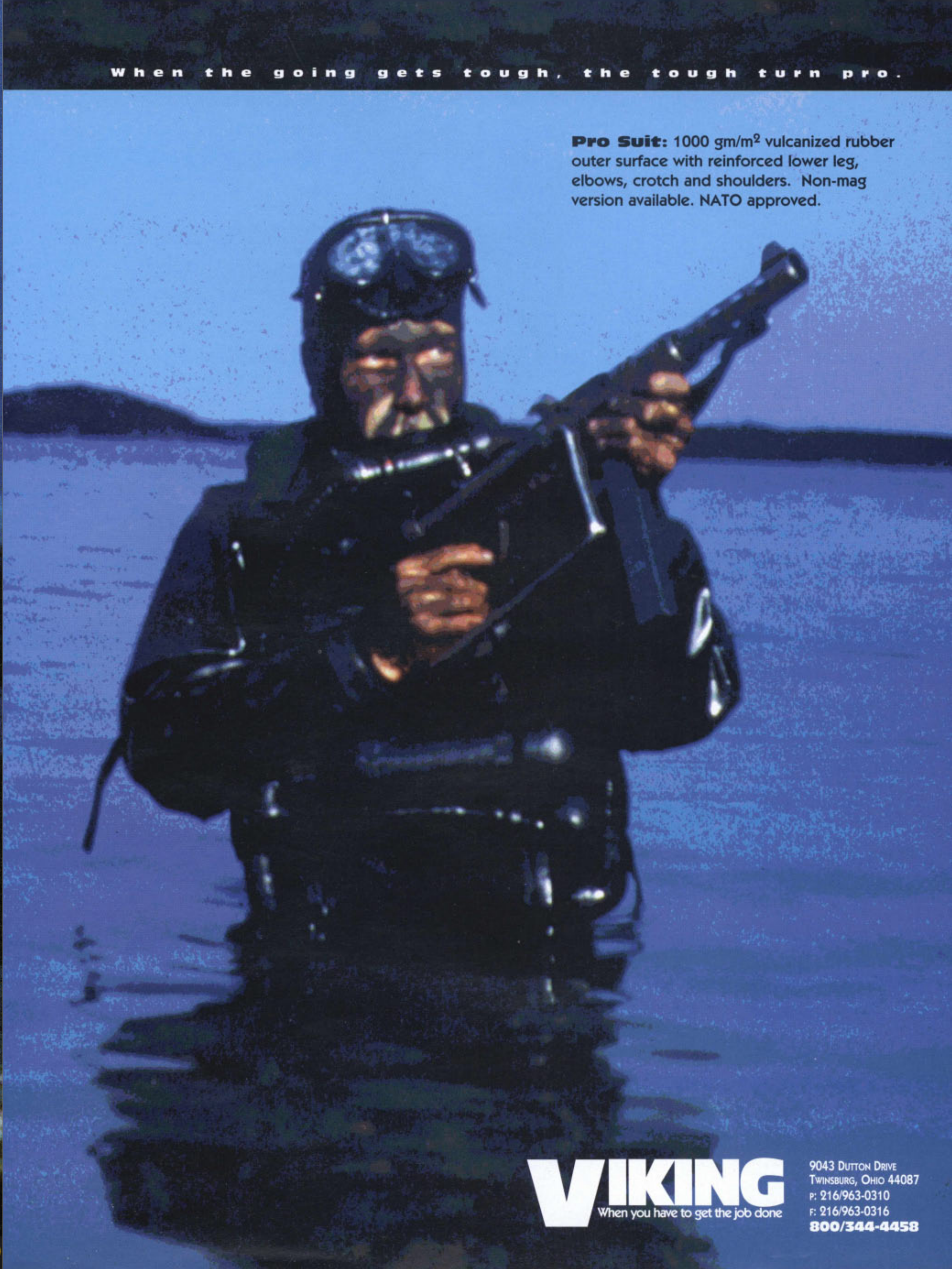

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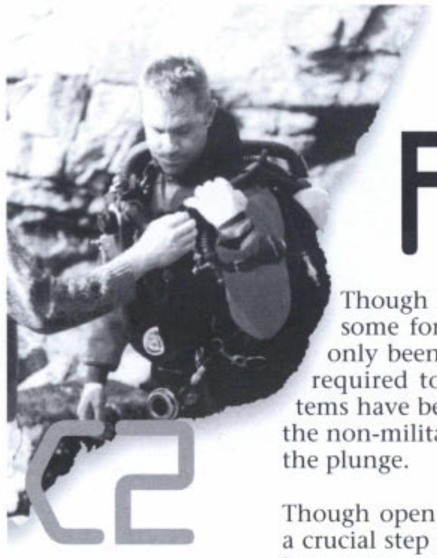
PHOTOGRAPHY

Cover—*Olivier Isler with the RI 2000 combined with a Carleton Technologies Mk-16 UBA. Isler; Bojan Brecel. Created by Mike Bielinski.*
M_2; David Krochford p.4, Electrolung; Walter Stark p.6/8, Isler; Bojan Brecel p. 7, habitat; G de Gendre p.10, glove; Arne Hodalic p.10, Shark; Howard Hall p.11, Blue hole; Rob Palmer p.12, Getting started; Simon Tapson p.15, turtle; Brian Skerry p.16, semi-closed; S. Clough, new kids; Jim King p.20, COBRA; Steve Linton p. 21, bailout; Melvin Kuamrul p. 24, BOS; Ph. A. TOCCO /Comex/ France, SCANUBA; Phillipe Roussan p.25, Cryogenic; SDM p.28, intervention; upper: R.W. Hamilton, lower; S. Clough p. 29, shadow; Tracy Robinette p. 30, LOOP; fore; Richard Nordstrom, mid: Jim King, back; Wes Skiles p. 29, computing; Richard Pyle p.37, cave; Bill Stone p.42, guru; Jim King p.43, repelling; Bill Stone p. 44, cornflkakes; Bill Stone p. 46, ropes; Barbara am Ende p. 47, gaggle of rebreathers; Chris Crumley p. 47,tunnel; Barbara am Ende p. 48, spare parts; Bill Stone p.48, tanks; Bill Stone p.48, ascending; Stone; Leo Dickinson p. 50,out; Bill Stone p. 85, check; Bill Stone p. 52, fins; Wes Skiles p. 53, Kristovich; Jim Bowden p. 64, Hutchinson; Tom Morris p. 65, dinosaurs; Fiorelli Photography p. 66, art; Bill Campbell pg. 66, shark; Brian Skerry, p.67.



"Like so many devices which at the time of their invention were considered too revolutionary, there was but little demand for diving apparatus of this type for many years. Although my company has been making large numbers of breathing apparatus on this principle for work in poisonous atmospheres, in mines, fire brigades, chemical works, gas works, etc. the demand for its application to the diving dress was comparatively small until the exigencies of war brought it into use and proved its value."

Robert H. Davis
Deep Diving and Submarine Operations, 1951.

First conceived of in the 17th century by Giovanni Borelli, closed circuit technology has long been considered revolutionary. For good reason.

Though rebreathers have been in operation in some form, since the turn of the century, it's only been the last 10 years that the electronics required to manage sophisticated control systems have been available, and less then that, since the non-military community has been ready to take the plunge.

Though open circuit "mix" diving has clearly been a crucial step in the evolution of self-contained diving—some would say 'uprising' — it can be argued that closed circuit, "C2" represents the real revolution that we have been waiting for. Today many technical and mission-oriented operations are pushing beyond the practical working limits of open circuit equipment, and the fact is, there is much more to be done. With a *virtually* unlimited gas supply—*read SAFETY*—optimal decompression, low bulk, and bubble-free silence, closed circuit is an idea whose time has surely come.

In spite of the promise held out by Sir Robert in the fifties, C2 technology never caught on in emerging commercial circles, which opted instead for the security of hoses and bells more suitable to construction diving. Meanwhile, the sport diving community has been content to "bubble" over the demand valve—*"new & improved"*— for the last fifty years. The result is that C2 has remained largely under the purview of the elite; a surprisingly small group of military users —"cave divers with money" as one observer put it—the group which has covertly driven the technology thus far.

Without new applications and the volume base to drive it, C2 development has remained essentially at a standstill for nearly twenty years; and its cost has limited accessibility to the few—*the chicken and the egg strike back*. In fact, all of the systems to date, whether prototypes or production models, have been hand-made, and hand-tested, making them collectible *objets d'arts,* with price tags to match. Now in the era of cheap chips and a potential wide range of new technically sophisticated users, all of that may be about to change.

Today there is a groundswell of interest in C2 technology and with it a new crop of entrepreneurs ready to pump out their latest creations, many of which represent the state of the art. Not to be upstaged, established C2 vendors are taking notice in light of dwindling military budgets and the promise of new buyers. All indications are that there are plenty to fill the bill; cave and wreck explorers, photographers, scientists and law enforcement divers— *the technical diving market.* There is even a renewed commercial interest in C2 for use in bailout systems. And if that were not enough, the Japanese have recently announced their intentions to put all of their bubblers "in the loop." *Detroit 2.0?* With some five to six million self-contained divers on the planet— the installed base of open circuit scuba— there appears to be ample volume to build a line. To put it into perspective, if "two to three tenths of one percent" of these divers bought a system at "one tenth" the going military price, it would double the existing market.

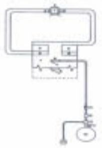
In spite of this fever to get into the loop, many formidable issues remain. Reliability, a long standing nemesis of rebreathers, is a key concern. Most military C2 applications involve short and shallow exposures making a reliable bailout less of a problem. That's not the case in commercial and technical applications. One contractor reportedly threw out a half a million dollars of closed circuit equipment in the '70s in the interest of his crew's safety. Not surprising, the tekno-entrepreneurs have taken up the gantlet and are leading the field with new redundant fault tolerant designs. Training is another sticky issue that needs to be worked out and the spectrum of opinion as to requirements seems to range from weekend rebreather courses to the full time, full mission profile scenarios favored by the military. Evidently, the truth lies somewhere in between. Worse is that liability insurance could end up being one of the real sticklers. One vendor estimated that liability insurance in the US— a product of the existing legal environment; *narcosis take two*—could run as high as US $5000 per unit, the low end of the range that many are targeting. Sticker shock? To be sure.

Price is clearly the issue that will make or break the market. As succinctly put by one PADI observer, "All that's needed is a price that a serious technical diver can afford." The good news is that there appears to be ample incentive to resolve this and other issues, "Where there's a dollar, there's usually a way." Start saving your money now.

The BIG question remaining then is, "When?" Though the technology is clearly here, the infrastructure needed to support it is not. Yet. According to one prospective vendor, "When the community really starts to feel strongly about closed circuit and wants to push for it, then it's going to happen." In other words, the future is in our hands.

What can you do (besides saving your money)? The first step is to educate yourself on C2 technology and it's capabilities— what it can do for your application. Next, and very important, start a dialogue with existing and prospective vendors (you'll find a convenient contact list to get you started on page 74); write them, call them, fax them, send e-mail— create a demand. Although the visionaries know they're on the money; the accountants need reassurance. That's what this issue of aquaCorps is all about. M^2

aquaCorps Journal N7 a.c C2



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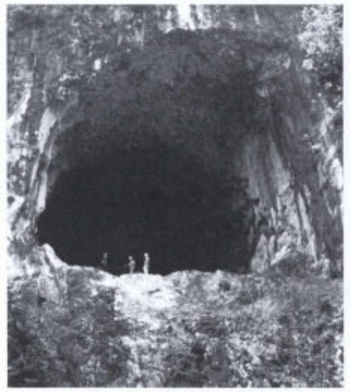

Welcome to San Agustin

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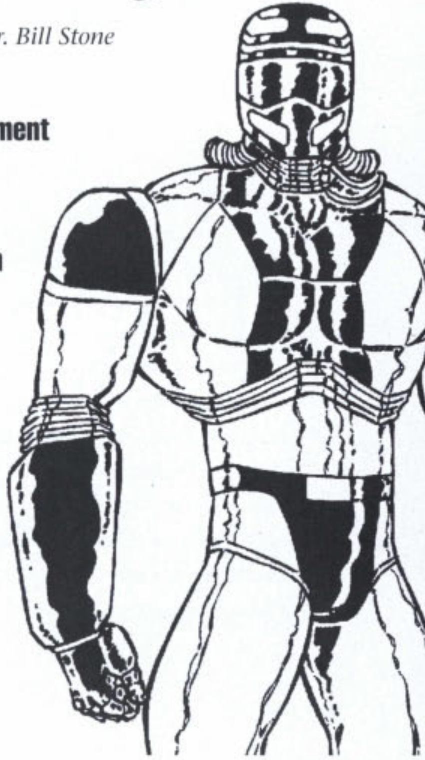

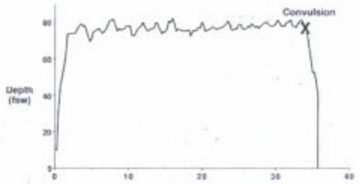

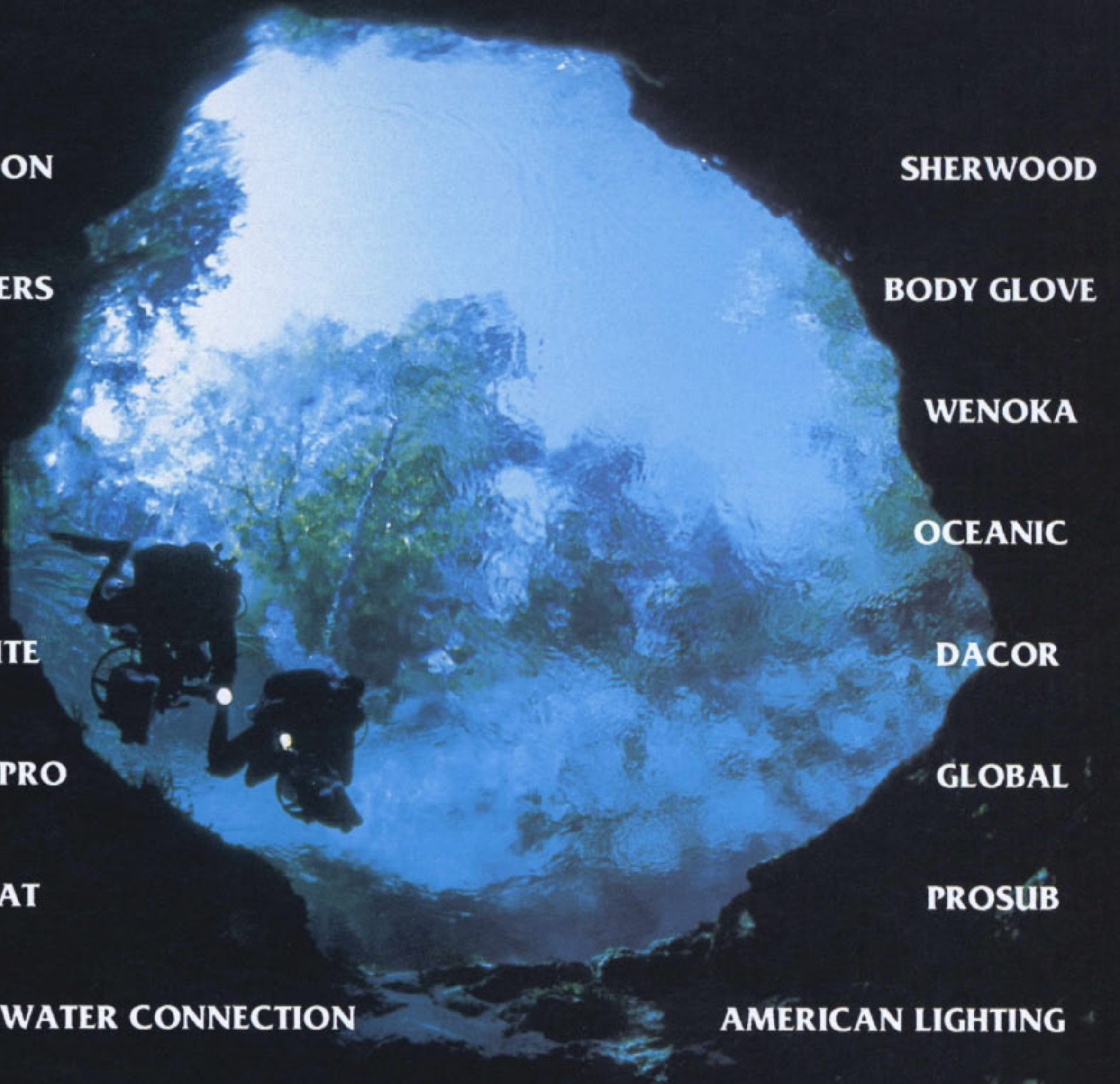

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aquaCorps. SPACE

South African Connection

Since talking to you while I was in the US over two years ago, my colleagues and I have been working towards our first venture in the world of technical diving. We have had to overcome many obstacles in the way of equipment and knowledge. Finally over the weekend of 29MAY93 we conducted two successful trimix dives to 250 fsw (76 msw) and 300 fsw (92 msw) at Danielskuil which is believed to be the deepest volcanic pipe in the world. Our bottom times were 12 and 8 minutes respectively. For our small group this is a major accomplishment, although our time at depth was relatively short. Without the the information and the contacts we have been able to establish through aquaCorps it would have taken us much longer to get where we are today and we certainly would not have had the breadth of knowledge we needed to make the operation as safe as possible.

Andy "Drew" Gray,
Rivonia, South Africa

To Air Is Human?

Hopefully the diving your way has been going well. We still have not got mix up and running over here (damn government intervention), but that can only be a matter of time. We still do air dives in the beyond the "accepted" limits. Unfortunately we had a fatality several weeks ago (see Incidents Report)—a 78 msw/254 fsw air dive that resulted in a CO2/O2 hit. Not a good thing! Do you guys ever use air at those depths or are ALL dives done on mix? If mix were not available would this dive be done on air in the US? To be honest, the site in question was a nice Paddle Steamer /Tug which sank in 1920 (the bell is most probably there!!) and I had a good dive, thanks to good planning and preparation. I am not asking you to condone the dive, but information on current practices regarding air dives (with oxygen decompression), preferably not just the "official" stance of the tech agencies,would be interesting.

Richard Taylor
Deep Diving Technologies
Sydney, Australia

Deep air dives (beyond 200 fsw/61 msw) are still be conducting in some circles though the overwhelming community consensus is that these dives are extremely hazardous and are becoming increasingly impossible to justify given the risks and availability of mix. This view is supported by the accident toll. Deep air kills. Of course there is still a small group of divers who **pride** *themselves on their ability to dive deep on air and survive. One individual—a mix instructor—recently told me that,* "There's only a handful of us that can handle air at those depths [beyond 90 msw/293 fsw]." *These individuals are a likely vanishing breed. We will be discussing air dives in the next issue of aquaCorps, N8, AIR. Stay pumped.*

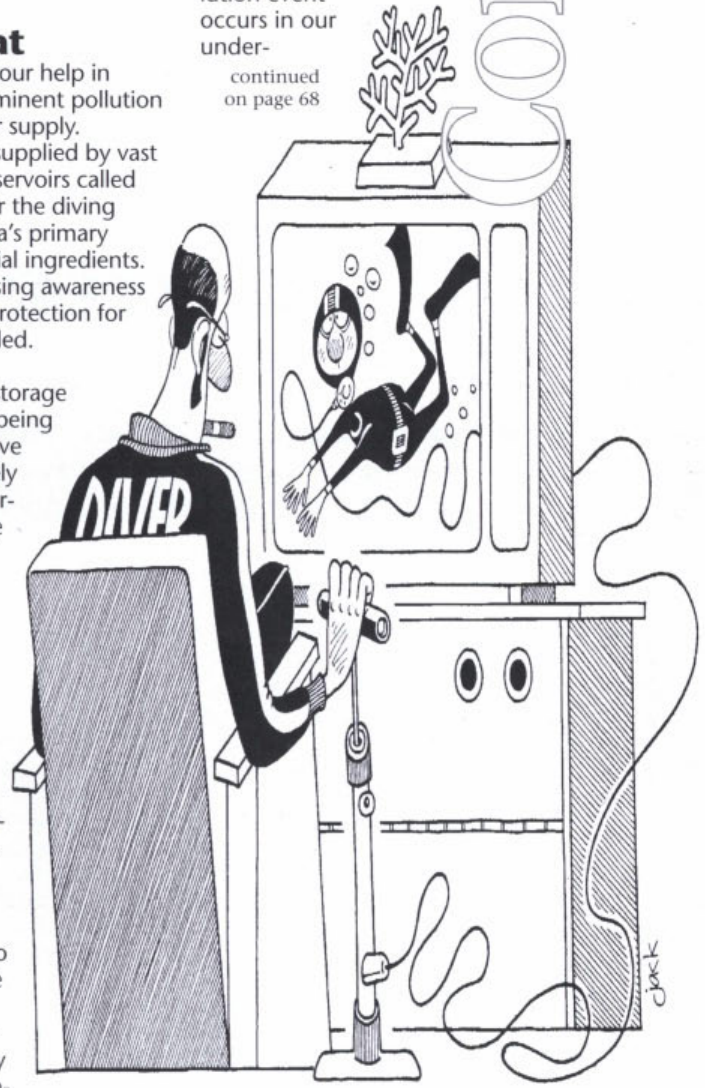
Imminent Threat

I am writing you to ask for your help in bringing attention to an imminent pollution threat to Florida's freshwater supply. Florida's springs and rivers, supplied by vast underground fresh water reservoirs called aquifers, are vital markets for the diving industry.They are also Florida's primary source of one of life's essential ingredients. aquaCorps' assistance in raising awareness and lobbying on behalf of protection for the aquifers is urgently needed.

Currently, a toxic chemical storage site and feeder pipeline are being planned in locations that have direct access to our extremely vulnerable aquifers. A consortium called Colonial Pipeline (comprised of AMOCO, TEXACO, CITGO, BP and others) plans to lay a gasoline pipeline across miles of wetlands and sinkholes near the town of Lloyd in Jefferson County, northeast of Tallahassee. The pipeline will supply a proposed gasoline tank farm to be owned and operated by TEXACO. The facility will be perched on a hill surrounded by four enormous siphons—major aquifer recharge points. Two other siphons are also in the same drainage area. Residents and local governments are under pressure by the powerful petroleum consortium to sell wetlands, swamps, and ground water recharge basins for the pipeline route and enormous gasoline tank farm.

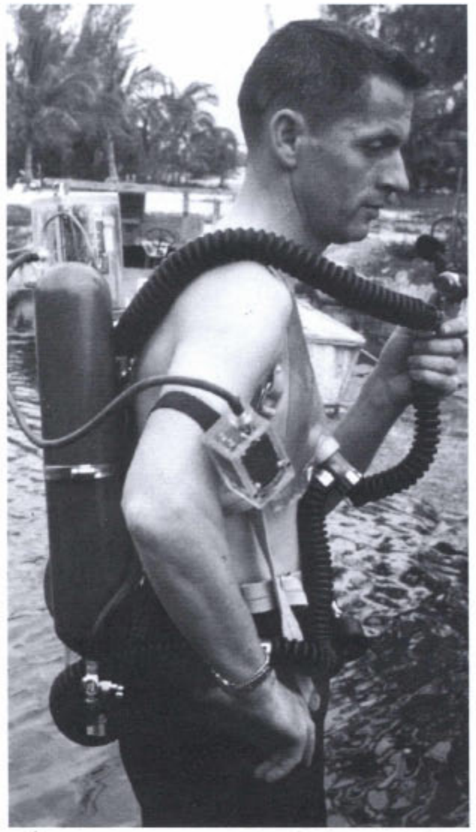
Dismal pollution records belie all the claims of "safety" made for facilities like these. A fire or any other accident that allowed gasoline off the planned site near Tallahassee would send thousands of gallons of gasoline directly into our drinking water. Because the mostly uncharted aquifers are underground, they have virtually no legal protection. When a pollution event occurs in our under-

continued on page 68



applications and environments

"I am convinced that technology is fairly neutral and that it can be placed in the service of dematerializing our culture which is the most important thing that we have to do to save our ass." Terence McKenna, Countdown To 2012, Magical Blend



Developed in the late sixties, the Electrolung, an early predecessor to the Biomarine CCR 1000 was the first commercially available, electronically controlled, closed circuit mixed gas diving apparatus.

ELECTROlung

by Walter A. Starck II

From the mid 1950's through the early 70's the exploration of a new frontier—*the ocean*—captured public attention. They were exciting times. Support for marine science expanded exponentially as the available technology underwent a quantum leap and self contained diving established itself as an important tool of marine science.

The changeover was not without resistance from the marine science establishment of the day who believed that diving was sport or adventure, not science. However, young upstarts like myself who had developed an interest in the oceans as a result of aqualung diving (the acronym SCUBA had not yet been coined) knew better. There were worlds going on down there there that our deck-bound professors couldn't even fathom. What's more is that their worst fears were true. We were having more fun on a weekend than they had in their whole careers.

At first we explored the shallower parts of reefs but by the late 50's the lure of the unknown had drawn me to the outer drop offs. Below 100 feet (30 meters) I found another whole world to explore, one stranger and less known than I had encountered in the shallows.

In the early 60's polarographic oxygen sensing electrodes appeared and I began to think in terms of a closed circuit, mixed gas scuba using the new electrodes to monitor and control the level of oxygen. For a few years the idea remained on the back burner while I completed my doctorate, participated in diving expeditions, and eventually started a company to produce some of the equipment I had developed. It was a bit like being a fat kid in a candy factory. There were simply more good things than I could do all at once.

In 1968, I had the opportunity to participate in the early use of *Deep Diver*, Edwin Link's first lock-out submarine. Aboard his vessel, *Sea Link*, I met John Kanwisher, an outstanding physiologist from Wood's Hole and Massachusetts Institute of Technology. John was also something of an electronics wizard who built most of his own instrumentation including simple, rugged and reliable polarographic oxygen electrodes. We were both impressed with the extravagant use of helium for open circuit deep diving and we began discussing the desirability and feasibility of building a closed circuit system. The basic parameters were quickly agreed upon. We would need three electrodes controlling a solenoid-operated valve governing oxygen input; circuitry to limit the effect of any electrode if its output differed from the others beyond prescribed limits, visual readouts for each electrode, an audible alarm triggered by high or low PO2 well within safe physiological limits, a dual battery supply for the electronics and a separate supply for the solenoid. The rest was plumbing.

Inert gas would be controlled manually since all that was required was making up volume lost on descent plus occasional top-ups for minor leakage around the mouthpiece and face mask and physiological absorption. There was also to be a manual bypass of the solenoid-operated valve on the oxygen side to enable manual control of PO2s in the event of failure of the solenoid valve and for oxygen decompression.

The overall configuration was to be a chest-mounted breathing bag and wrist-mounted sensor readouts with the rest in a triple cylinder backpack. The latter consisted of a central cylinder containing the CO2 absorbent, sensors, electronics, solenoid valve and batteries. Flanking it were bottles for the oxygen and the inert gas diluent.

Within a few weeks of returning home to the Florida Keys, I had the hardware together and John had posted me a breadboard prototype of the electronics. I installed the circuitry and after a few minor adjustments to the solenoid, everything worked. We dubbed it the "Electrolung." Over the next year we refined the design and readied it for production. During the same period I took delivery of *El Torito*, a 104-ton vessel built especially for my work. With the new vessel I carried out extensive diving with the Electrolung in the Bahamas and the western Caribbean.

The Electrolung performed beautifully. It provided up to six hours duration while using less than 10 cf of inert gas. Totally unexplored realms were mine to explore. Decompression was the biggest problem. The only readily available tables were the antiquated US Navy heliox tables and even these required some adjustment for use with the Electrolung. The tables were based on a constant percentage of O_2 while the Electrolung maintained a constant partial pressure resulting in a variable percentage depending on depth.

continues on page 8

MEASURED Elegance

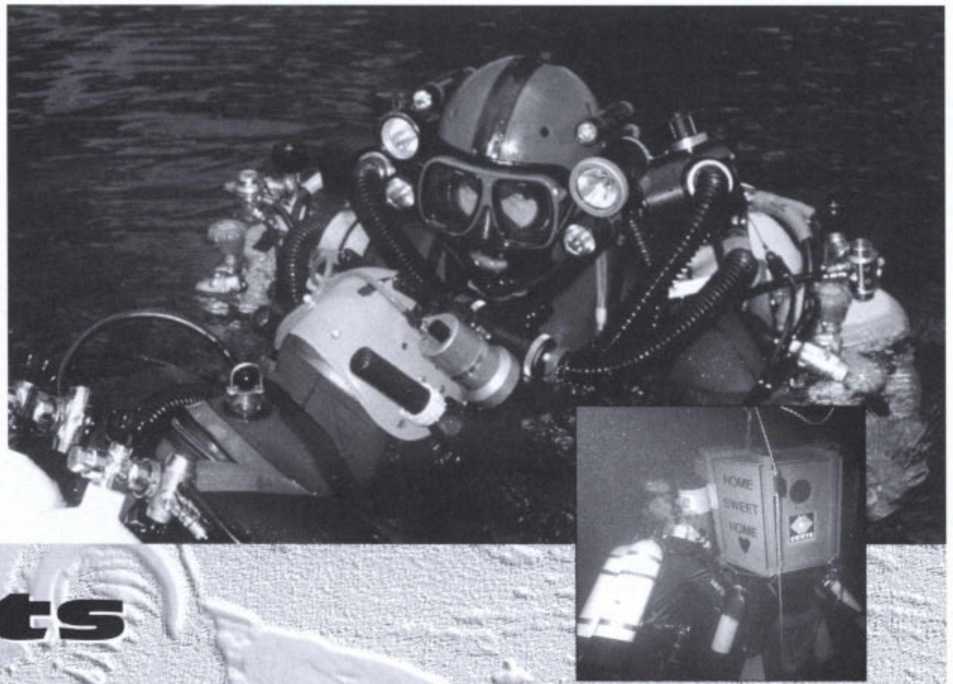
by Olivier Isler

On 31 December 1989, I completed what I believed to be the first major dive in a siphon using a semi-closed circuit system designed and conceived for that purpose. Eighteen months later I was astonished (as was the European cave diving community) to learn that Jochen Hasenmayer had made a number of remarkable dives using a rebreather some nine years earlier as reported in *The Darkness Beckons: The History and Development of Cave Diving*, by Martin Farr.

I shall steer well clear of criticizing the renowned Hasenmayer, who will certainly remain one of the greatest pioneers of cave diving. However, whilst my original assertion now seems unsound as a result of the lack of information on my part (Hasenmayer was always very secretive), I still believe deep down that I am right. Hasenmayer's most outstanding dives were conducted using open circuit technology, perhaps indicating a lack of faith in his new device. In my case the reverse applied.

At least three factors contributed to my decision to seek a different technological approach to underground exploration beginning with the existence of an extraordinary siphon, La Doux de Coly. In 1984 I penetrated a distance of 3100 metres/10,170 feet in that source with the average depth of nearly 50 metres/163 feet. I accomplished this with an enormous back mounted aqualung (five 20 litre cylinders, or 23 cubic metres of gas—about 812 cf) along with many more cylinders for back-up and emergency. I could have continued the push but it would have required a massive investment of energy. Very long dives would be necessary to place and retrieve the necessary stage cylinders before and after the main exploration push. These would have called for a formidable team of assistants serving a single exploration diver, much like the old Himalayas expeditions. Instead, I wanted to bring a measure of elegance to the way La Doux De Coly and other underwater caves are explored. La Doux De Coly provided the needed impetus to develop a unique type of self-contained aqualung.

The second contributing factor was a physiological handicap. Being very tall and weighing 78 kg (172 pounds) presents a drawback from a physiological standpoint since my body's metabolism requires a substantial intake of oxygen. In quantitative terms, I use approximately 25 litres of gas per minute (about 0.9 cf) when swimming underground. With a rebreather, this problem no longer exists.



Designing a life support apparatus is one thing; using it to venture into an unknown siphon is quite another. Our first dives were somewhat stressful from a psychological standpoint because of the experimental nature of the equipment. Looking back over the dives we conducted and analyzing the parameters of long stays underwater, it was clearly much safer to set off with the RI 2000 on one's back; if only because of the fact that a tiny part of the systems capabilities were actually used. In spite its many deficiencies, we believe that this aqualung will have played a minor but unquestionably significant part in the history of diving exploration.

Thirdly, I had the good fortune to meet Alain Ronjat, an electronics engineer who was fascinated by the intricacies of breathing apparatus. Between us, with just over 5000 hours of hard labour, we designed the Ronjat Isler semi-closed system, which we named the RI 2000.

The choice of a semi-closed circuit system

In theory, closed circuit technology would seem to be the obvious choice for exploration as it offers maximum performance, reduced weight (for the same weight, a closed-circuit system lasts about four times as long as its semi-closed counterpart), a constant partial oxygen pressure that can be set at an optimal level for the environment and the ability to carry out the total decompression with a single system (i.e. no need for additional cylinders).

In practice, however, the advantages of closed circuit proved less devastating than one might have imagined, whilst the semi-closed system has two advantages that are of critical importance for a small team of amateurs beginning with simplicity. The design of a reliable closed circuit system requires a considerable investment in human and financial resources. This is not the case with semi-closed technology. Moreover, the complexity of closed circuit systems inevitably brings greater risks of failure in operation.

A further advantage is the fact that the system uses pre-planned gas mixes with known characteristics. This makes it possible to return to safety even in the event of a serious failure in the electromechanical system.

The RI 2000

The RI 2000 is actually a version of the semi-closed systems currently in use by the French Navy that has been adapted for cave diving.

continues on page 10

ELECTROlung

continued from page 6

While delving into the decompression literature, I came across a paper by Dr. Brian Hills expounding a radically different model for decompression, that of thermodynamic equilibrium. Hills came into physiology from a background in physical chemistry and his paper was full of abstruse mathematics. After reading it at least three times I began to understand what he was talking about and it made sense to me.

From a practical point the essence of Hill's argument was that there is no such thing as a safe level of supersaturation of dissolved gas. Conventional decompression procedures were creating a sub-symptomatic case of the bends with a too fast ascent to a too shallow first stop which was then offset by a lengthy stay at shallower stops. He proposed that shorter and more reliable decompressions could be achieved by a slower ascent with both first and last stops at greater depth. There was of course much more to Hill's ideas, the subject of an entire doctoral thesis, and to this day, his work has still not received the recognition it deserves.

With a double-lock 300-ft. recompression chamber aboard *El Torito*, I felt we could experiment a bit. Drawing upon Hills' model, we eventually proved out a dive profile involving 300 fsw (92 msw) exposure for 15 minutes with 15 minutes of decompression.

In 1969, we entered the market with the Electrolung at just under US$2000. At first we sold only to select customers whom I felt had the "instrument-sense" to use such a device. Late that year, however, Beckman Instruments made us an offer for the rights to out entire product line. Not really wanting to spend full time in manufacturing and enticed by the resources Beckman had to offer for further development, it was an offer I couldn't refuse.

Under Beckman, further improvements were made to the Electrolung and sales expanded. Users included commercial divers, foreign and domestic defense forces, intelligence organizations, and even NASA for use at their weightless simulation facility. Among the initial users were also what were then called **"pro-divers,"** experienced divers from the professional or semi-professional end of sport diving, the forerunners of today's technical diving community.

In 1970, three deaths occurred with the Electrolung involving pro-divers. In two of the instances the preponderance of evidence pointed to operator error. In the third case there was no indication of causation. Lawsuits ensued and Beckman faced some hard questions. Did the profit potential justify the liability risk? Were they willing to continue selling a product that might kill a significant number of users?

By this time the earlier excitement over oceanic exploration had also waned. Wealth from the seas promised by promoters of marine research and exploration had not materialized. In corporate and government circles diving expenditures were beginning to look more like throwing money into the sea rather than an investment. Funding began to be cut back.

Beckman decided to get out of their oceanic products division entirely. The rights to the Electrolung reverted to me. After production of the Electrolung ceased, its operational use continued successfully for some years. During its lifetime, it was employed in a broad range of diving including deep saturation and a rumored lockout from a nuclear sub at 1000 feet (307 msw) in the Arctic Ocean. My decision was simpler and was already made. I headed *El Torito* for the South Pacific where I spent the next 20 years diving and exploring further facets of life.

Despite subsequent advances, closed circuit mixed gas systems have yet to move into the mainstream of diving technology and are unlikely to do so in the foreseeable future. Regardless of reliability, they are inherently dangerous. With proper care, attention and operation, they can be used very successfully, but any lapse can prove fatal.

Closed circuit systems are not so much a breathing apparatus as they are a complex instrument. Requirements for effective use are a bit like flying an aircraft. Meticulous maintenance and preparation, a thorough functional understanding of the unit, training to the point that handling is reflexive, the ability to make decisions quickly, coolly, and correctly under stress are all necessary. Most importantly, the user must pay attention at all times to what they are doing and the functioning of the apparatus. Finally, in any uncertainty, the user must err on the side of caution. There are old pilots and bold pilots, but there are no old bold pilots.

Not everyone has these abilities. Probably most don't to the degree required. As a result closed circuit mixed gas systems are likely to remain at the periphery of diving for now.

Dr. Walter Stark is the author of numerous books, articles and scientific papers and has produced ten television documentaries on his explorations. In addition to the Electrolung, he was the co-inventor of the Bangstick and one of the originators of the use of underwater dome ports for use with wide angle lenses. Stark can be contacted at: PMB 1, Daintree, Queensland 4873 Australia.

Elegance

continued from page 7

Long hours of difficult work were carried out to accomplish this focusing on three main features: ease of breathing, safety and performance.

Ease of breathing is critical in the hostile environment of cave diving where water flow can precipitate shortness of breath and increase CO_2 levels. Our modifications included the addition of an electronically-controlled solenoid valve in order to stabilize the partial oxygen pressure in the breathing mixture. This eliminated the breathing discomfort caused by mechanical leakage. In addition we increased the cross-section of the end couplings, injectors and filter cartridges in order to reduce load loss and carefully positioned the breathing bag in the back pack to be at virtually equal pressure with the lungs.

To increase safety, the RI 2000 was designed to accommodate three fully-independent circuits: two dorsal and one ventral **(see photo)**. The latter may be removed to reduce the physical bulk of the diver when considerable freedom of movement is necessary to perform a particular task. In addition, great attention was paid to pack protection and duplication of the injectors for each circuit. Finally, the use of two different mixtures in the six cylinders of the set allows three cylinders to be allocated for each mixture, thus any of the three circuits available can be fed using snap-fit couplings.

The performance of a semi-closed system depends on the flexibility of the respiratory circuit as well as the depth and the quantity of gas carried.

The latest version of our system, Evolution II affords great flexibility than earlier models and can be used for depths of up to 100 metres (325 fsw) or more. The duration time at maximum depth is around 7 hours in accordance with the Rule of Thirds (Use 1/3 of the gas for penetration, 1/3 for the return, 1/3 is held in reserve—ed). At a depth of 50 metres (163 fsw), the duration time is about 12 hours.

Operations

The RI 2000 is extremely comfortable when diving but the potential user requires a period of training. Compared to a conventional aqualung, this new apparatus requires sensitive handling and sustained concentration on the part of the diver. Mishandling when changing an end coupling or gaseous mixture can entail serious consequences. In addition, preparing the set for operation demands great care and more time than an open-circuit system, for example in packing the soda lime scrubbing agent. It is also advisable to plan and train for "disaster scenarios"; for example a failure of the entire electromechanical system in the three circuits (fortunately, an uncommon occurrence!).

The system was conceived and designed for long-distance diving. It is therefore heavy (115 kg—about 254 pounds) and relatively bulky, which means that the diver cannot get out of the water alone, for example, after crossing a siphon. However, when submerged its hydrodynamic characteristics are most satisfactory and enable the diver to swim 25 metres/minute (82 fpm) without too much effort, or to straddle two coupled boosters (stage bottles) with great comfort.

Though performance levels are significantly less than those of closed circuit systems, the RI 2000 greatly expands the options offered by conventional open circuit scuba. In theory, it is possible to conceive of dives well in excess of 24 hours. However other physiological limitations apply particularly with respect to thermal considerations. Except in the rare case of a very temperate environment (water temperature above about 28-30° C or 82-86°F), wearing a dry suit is an essential requirement. In Europe, where the water temperature generally fluctuates between 7-13°C (44-55°F) the thermal comfort of the diver is of paramount importance. Even minor details become significant. That is one reason I developed a system for urinating outside my dry suit. This addition dispels the abominable odor and avoids the need to undergo lengthy decompression stages with very chilled feet!

The Future

For a number of the reasons outlined above, the future of the RI 2000 is unclear. Whatever the outcome, we believe it will have established itself as a precursor for major operations in the years ahead. Such operations will inevitably become increasingly sophisticated from a professional standpoint and will require considerable investments in terms of human and material resources, thus making them less accessible to amateur divers. This is of course regrettable, but a wholly logical progression.

With regard to the future prospects of rebreathers for sport diving applications, I believe their widespread adoption is unlikely. Indeed, it seems that only extreme situations fully justify their use. For "standard" diving such equipment represents an unnecessary and costly luxury.

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AUTHORS NOTE

Designing a life support apparatus is one thing; using it to venture into an unknown siphon is quite another. Our first dives were somewhat stressful from a psychological standpoint because of the experimental nature of the equipment. Looking back over the dives we conducted and analyzing the parameters of long stays underwater, it was clearly much safer to set off with the RI 2000 on one's back; if only because of the fact that a tiny part of the systems capabilities were actually used. In spite its many deficiencies, we believe that this aqualung will have played a minor but unquestionably significant part in the history of diving exploration.

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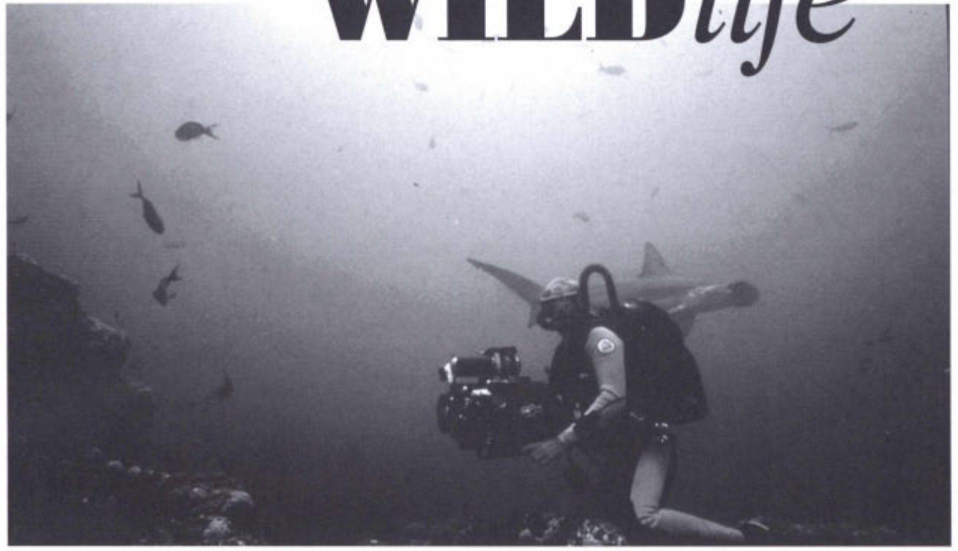
hammerhead

WILD*life*

by Bob Cranston



In the Summer of 1990, Howard Hall and I traveled to Biomarine in Philadelphia, PA to train on the SeaPac MK-155 mixed gas closed circuit rebreather (CCR), the civilian version of the MK-16. We planned to use this equipment to film hammerhead sharks in the Sea of Cortez which are normally difficult to approach.

First as a result of practice dives we made several modifications to the military-configured CCRs. We removed the complicated harness rigging and mounted each system onto a modified ScubaPro BC, since they had no buoyancy system. We also rigged a 15 cubic foot bailout bottle in case of a complete system failure.

On location in the Sea of Cortez, we made two dives a day for ten days. Our dives ranged from two to four hours each, with depths from 60 to 130 feet /18-40 msw. During operations we experienced failures in the primary and secondary instruments and in the electronics. However, operating the system manually—a standard emergency procedure—was fairly easy. The units were cumbersome for swimming, but we only had to make it down to the top of a sea mount and wait for the sharks to come to us.

We were successful in obtaining the film we needed of schooling hammerhead sharks. In fact, we have the only film in existence of mating hammerhead sharks. This was due largely to the closed circuit systems. The silence and lack of bubbles characteristic of the CCRs allowed us to position ourselves in the path of the approaching school of hammerheads and film them unnoticed. We were able to go to the depths necessary, stay there long enough to get in position, and get the film we needed. The job proved to us that the rebreathers could be very useful in approaching and filming wildlife that normally shies away from the roaring noise of exhaled bubbles. However, we also learned the limitations of the systems for film projects.

First of all, the automatic controls on the system were subject to failure. Accordingly, the operator must be able to operate the units manually, have backup plans in mind, and be able to implement them quickly and smoothly. Also the design of the SeaPac 155 makes it difficult to swim with. The units themselves weigh about 60 pounds and the support equipment weighs another 60; something to consider when traveling. Performing a controlled ascent or descent is simple enough, but keeping up with a swimming marine animal while pushing a big film camera proved to be a problem. Fortunately, the sharks came to us.

Unlike open circuit diving, the time investment in training and maintaining a closed circuit system is significant. In addition to extensive training, each CCR unit required one to two hours to *prepare* and then another 30 minutes *after each dive* to disassemble and clean. Spare parts and consumables were an additional consideration.

Despite the disadvantages, the overwhelming benefit of being acoustically invisible to other animals in the water makes rebreathers an irresistible piece of gear for film makers. We chose the SeaPac 155 because it is one of the few proven systems on the market with a real track record. Also the work of breathing is minimal due to a good counter-lung and scrubber design. Our present capability is seven hours continuous dive time. We are willing to dive the units to about 350 fsw /107 msw. We generally run our partial pressure of oxygen at 1.2 atm, using air as a diluent and can dive in total silence to 60 feet/18 metres for 200 minutes, or 70 feet/21 metres for 100 minutes with no decompression at all. The result is that we have had many satisfying dives filming both large and small sea creatures who never even knew we were there!

Over the last few years we have made numerous changes to our CCRs in order to optimize them for film work. We have increased counter-lung capacity and integrated an open circuit bailout system within the unit. One of our best improvements so far has been moving the weight and center of gravity within the unit itself. This has made a tremendous difference in swimmer dynamics.

Some of the future improvements we would like to make but have not yet completed are to reduce the overall size of the unit even if this means sacrificing overall dive duration. In addition, we would like the ability to change the partial pressure of oxygen during the dive so we can take advantage of variable oxygen pressures. Finally we would like to have an integrated dive computer that calculates decompression time based upon the oxygen set point.

It should be noted that our enthusiasm for closed circuit systems does not extend to the point of recklessness. Rebreathers cannot be used is a casual way. It is not just a matter of being a good diver who is comfortable in the water; a high level of awareness and confidence with the equipment is required along with substantial hours of practice. In preparing for our next film project, Howard and I are diving our rigs every week and are constantly making improvements in our technique and the systems themselves. Many hours of training are required to achieve the necessary level of proficiency.

Rebreathers are attractive for a number of specific jobs including film work, scientific research, and military use, but I don't foresee their wide spread use by average divers anytime soon. The equipment is expensive and is not readily available. What's more is that liability is still a key concern.

In spite of these obstacles, the tremendous advantages of rebreathers make their advance inevitable in the diving community. Using rebreathers for only ten days, we were able to document more hammerhead shark behavior than scientists have been able to capture in years of free diving research. With so much of the ocean yet to be documented, it's an exciting time to make films. And, Howard and I, will be hot on the trail without leaving a bubble.

Trained in commercial mixed gas and closed circuit diving, wildlife photographer, Bob Cranston has earned a reputation for his knowledge of sharks. Working with Howard Hall Productions, he has filmed noted documentaries including Seasons of the Sea, Shadow in a Desert Sea, *and* Dolphins, Whales and Us. *Cranston can be contacted at: 13815 Corte Ganso, San Diego, CA 92129-2181, fax: 619.484.6184.*

BLUE HOLE

by Rob Palmer.

In 1987, I headed a cave diving expedition to Andros Island in the Bahamas to continue the exploration of many of the Blue Holes we had encountered during previous expeditions to the area. We had a large scientific contingent and part of the programme was to recover deep wall rock and speleothem samples for research on climactic history and diagenetic processes. We looked at several possible ways of working at depths of up to 100 metres/325 feet in remote caves which are often at a considerable distance from the nearest road. Surface umbilicals and one-atmosphere suits were ruled out almost immediately. Open-circuit scuba was a possibility but air wasn't. The amount of helium and oxygen on site that we would needed for open-circuit operations was not only daunting, but exceedingly expensive. That left rebreathers.

Stuart Clough generously provided several Carmellan Research CR155 units. These were modified Rexnard Mk-15s adjusted to run a partial pressure of 1.4 bars of oxygen (*1 bar =1.013 atm so for physiological purposes they can be treated essentially the same—ed.*). These gave us the potential of long bottom times with reduced decompression and no narcosis—an ideal blend. Because we had no prior experience using these systems in caves, we made it a rule to carry a bail-out cylinder of pre-mixed heliox rated for breathing at our target depth. On the return, an umbilical was hung from the entrance to a 21 metre/70 foot depth to provide a back-up gas feed and the ability to decompress from 9 metres/30 feet on open-circuit oxygen (*Note that 6 msw/20 fsw is recommended as the maximum depth for oxygen decompression in the absence of a full face mask, though some European explorers pull their stops slightly deeper—Ed.*). Our main target, *Stargate*, hit 92 metres/300 feet below the entrance, where we conducted numerous safe and successful collection dives on the rebreathers.

Two years later we were making 100 metre/325 foot closed circuit dives in remote open water Blue Holes on Grand Bahamas working out of Zodiac inflatable with a two or three man support crew on the surface. Oxygen decompressions were made on an umbilical or using stage bottles. More dives followed, including biological collection runs for medical research in the Tongue of the Ocean at around the 80-90 metre/250-300 foot mark. It was reassuring to breathe a gas that allows you to think and be fully aware of your surroundings while at the same time not have to be constantly checking a pressure gauge.

Our most recent closed circuit project was an archaeological recovery collecting Lucayan Indian remains in an Andros Blue Hole. For this project we used the rebreathers at much shallower depths, between 20-40 metres/60-120 feet. It afforded us bottom times of between an hour and an hour and a half without more than a few minutes decompression. We could have spent all morning at the 20 metre level without needing to decompress at all. Using heliox and running a PO2 of 1.4 bar meant that we could make repetitive dives after only a five hour surface interval without any additional time penalty. There was the added bonus of excellent visibility despite the cave roof being covered in a fine bacterial mat. No bubbles meant no disturbance up above. Also working close to the entrance allowed us to use a small 25 cf bailout cylinder rather than a 90 cf stage bottle. An oxygen cylinder was staged at 6 metres/20 feet and all stops were done there on pure O_2. Though clearly within the air range, conducting these exposures on open-circuit scuba would have meant a lot of decompression, poor visibility and a fair number of cylinders and compressor hours.

Rebreathers have taken a long time to come of age. Never the less, deep diving remains a serious business. Constant partial pressure tables aren't exactly commonplace and the ones we were using, developed for Carmellan by Hamilton Research Ltd, were still effectively being tested. We were the guinea pigs. Fortunately we took the added precaution of having Dr. Hamilton and computer on site in case of an emergency abort.

The advent of next generation closed circuit systems will likely push the self-contained diving envelope back a lot further. While it may be exciting to make a 100 metre open circuit jump on a wreck or push the same gear with lots of staging posts into deep, long caves, open circuit will likely become obsolete For deep open water dives use a rebreather. But remember for long, remote exposures the old rules of redundancy still apply. Take two.

Rob Palmer is one of Britain's well known cave and technical divers. Director of the Andros Project and author of three books, *he is currently the Special Projects Director of Carmellan Research Ltd, and Managing Director of Technical Diving Ltd. He can be contacted at: Neighbourne Cottage, Neighbourne, Oakhill, Somerset. BA3 5BQ. UK. f: 0749.840.685.*

REBREATHER PRIMER

By R.W. "Bill" Hamilton

What is a Rebreather?

Unlike most of the names technical divers use for their equipment, the word "rebreather" is both simple and descriptive. A rebreather is a breathing system that enables the user to retain and reuse some or all of her expired gas.

To be suitable for reuse, the expired gas has to be processed to some extent—a function performed by the portable processing unit that comprises part of the rebreather. In contrast, a device that saves and reprocesses the expired gas remotely from the diver is generally called a "reclaim" system. These are designed for commercial bell operations and are not of interest here.

Humans operate optimally at an oxygen partial pressure (PO2) of about 0.2 bars (or atmospheres)[1] with some "inert" background gas making up the balance, and without too much CO2. The rebreather reuses expired gas while maintaining these limits.

Even though oxygen is the most vital gas physiologically speaking, the inert gas is also important in this discussion because oxygen must be diluted with some other gas when at an absolute pressure much beyond about 1. 5 bars (in terms of depth, beyond about 20 fsw or 6 msw). Of course, the inert gas is also important to decompression, since it is the source of decompression problems, and technical diving includes a lot of tricks to try to reduce it.

The inert gas component is crucial in rebreathers, because its conservation is the main purpose of the unit. In addition to conserving inert gas, the rebreather has several other tasks. The first is to provide an appropriate oxygen level. In addition it has to remove carbon dioxide (CO2). Finally, it must provide an expandable space for the diver to breathe in and out of.

Carbon Dioxide Removal

Carbon dioxide is a normal product of body metabolism. It is usually given off at a level of about 0.8 times the amount of oxygen consumed. For practical purposes, a rebreather has to remove about one liter of CO2 for each liter of oxygen consumed in the body. This is not the amount of oxygen *breathed*, but the amount *consumed*.

Carbon dioxide is relatively easy to remove, and most rebreathers do this well during low or moderate work levels by passing the expired gas through a canister filled with chemical absorbent such as soda lime. However, when the canister gets cold, the absorbent becomes far less effective—enough so as to create a serious problem under certain conditions. This ongoing problem has been dealt with by redesign of the chemistry and physical structure of the absorbent, or by warming the canister—itself a difficult task.

Most standards call for CO2 to be kept below about 0.5 kPa (they usually say "below 0.5% sea level equivalent," which is the same as a partial pressure of 0.5 kPa).[2] Lower CO2 levels than this are no problem, and higher levels to about 3 kPa may be distracting, but are tolerable, although they can lead to serious problems if the diver exercises, and can increase sensitivity to CNS oxygen poisoning. Excess CO2 causes an increase in the urge to breathe, and above levels of 15 kPa or so can cause severe narcosis, unconsciousness, and convulsions.

Oxygen Control

The task of controlling oxygen is much more complex than regulating CO2 levels. This gas has to be kept between strict upper and lower limits for physiological safety, but there is a strong incentive to run the oxygen level as high as possible to improve decompression.

While the oxygen level can be as low as the familiar 0.21 bars PO2 (21% at sea level), there are advantages to having it higher. First, should the level fall below about 0.10 to 0.12 bars, the diver may suffer symptoms of hypoxia (oxygen starvation). Below this, it can cause unconsciousness, and if the oxygen level gets too low, it can be fatal. Maintaining a PO2 higher than 0.21 bars makes hypoxia less likely.

In the other direction, it is necessary to keep the oxygen below the level that could cause oxygen toxicity. The degree of any oxygen toxicity is a function of both oxygen level and duration of exposure. The main toxicity problem is a neurological one: the risk of a convulsion. This type of nervous system (CNS) toxicity is a relatively short-term effect. Another manifestation of oxygen toxicity is a general effect on much of the rest of the body besides the central nervous system—particularly the lungs—resulting from longer exposures at somewhat lower levels of PO2 than cause convulsions.

From an optimal decompression perspective, a technique that has been found to be effective is to maintain a PO2 of near to but no greater than 1.4 bars. This is safely below the threshold for CNS toxicity, and this level can be tolerated for the duration of all practical rebreather runs (assuming a high degree of control is maintained; a lower level is recommended during early trials or training). It gives near-optimal decompression because the oxygen is about as high as can be tolerated for the entire run, but there is minimal concern about CNS toxicity as long as the rebreather works properly and depth is controlled. (*Note that the USN currently specifies a "set point"—the target PO2 level—at 0.7 bar, though they are considering raising this to 1.2-1.3 bar—see Oxygen Exposure Management by Richard Vann pg. 54. Other working groups such as San Agustin Expedition led by Dr. Bill Stone, Stoned, pg. 42, are running their PO2s at 1.0—ed.*)

The Counterlung

One critical function of a rebreather is to provide a "counterlung"—a kind of breathing bag for the diver to breathe in and out of. This cannot be a rigid space, and it has to be as large as the largest expected breath. In addition to the counterlung, the rebreather hardware must include absorbent canisters, a means of regulating gas flow, a housing pack of some sort, gas storage, and a mouthpiece or mask.

Regulation of the rebreather's counterlung function is affected by changes in depth, and this can be the source of some problems. As depth changes, the rebreather unit must adjust to both a change in the gas volume and a change in the oxygen fraction in order to maintain counterlung volume and a constant PO2. Thus, ascents cause a

> "No children ever opened a Christmas present with more excitement than ours when we unpacked the first "aqualung." If it worked, diving could be revolutionized."
> Capt. J.Y. Cousteau
> with Frederic Dumas,
> The Silent World, 1953

release of bubbles (since gas cannot be put back into the high pressure containers) and descents require addition of gas to maintain system volume. As a result, too many depth changes can deplete the gas supply even though the diver does not actually use gas. Another problem is the placement of the breathing bag relative to the lungs. If it is above the lungs, it is harder to breathe; and if below, the gas is under slight positive pressure. This, of course, may change when the diver shifts position.

Types of Rebreathers

In general there are two main categories of mixed gas rebreathers: closed and semiclosed. Closed rebreathers all have oxygen controllers that sample the gas in the breathing circuit and add oxygen or inert gas as needed by operating a solenoid valve or its equivalent.

Semiclosed units work by feeding a preplanned oxygen-rich mix into the breathing loop usually at a rate adjusted to match the consumption by the diver. Semiclosed units are of two main types: those that control oxygen input by flow control, such as passing the gas through a calibrated orifice, and those that use the counterlung to adjust the gas by a mechanical ratchet or bellows arrangement.

Systems with oxygen controllers normally use pure oxygen for the oxygen supply, but rather than use pure inert gas they usually rely on a diluent mixture with a small amount of oxygen in it that can sustain life in the event of a failure of the oxygen supply. As a result, the operating range of these units is generally not limited by the gas mixture. However, oxygen-controlled rebreathers are sensitive to exercise rate, and the design must prevent a high oxygen demand from depleting the breathing loop of oxygen.

Semiclosed units usually use only one gas mix, and a given mix is limited to a specific depth range in order to stay within oxygen limits. The mix used is somewhat higher than the desired oxygen level and is bled into the loop at a controlled rate that must be somehow matched to the exercise level and hence the oxygen consumption of the diver. These units are much more sensitive to oxygen demand than units with an oxygen controller.

Still another type of rebreather is the pure oxygen unit. This apparatus needs no oxygen controller nor inert gas, but is limited in depth because of oxygen toxicity. This type of unit requires supreme care because exceeding the depth limit (about 20 fsw or 6msw)can result in CNS toxicity. Because of its limited depth capability these units are of limited value for most divers, but they might be attractive for oxygen breathing during decompression and for special applications such as law enforcement and scientific diving.

What Are Rebreathers Good For?

The most obvious use of the rebreather is to provide extended diving time independent of gas supply. This in turn allows longer bottom times than can be obtained with carried gas, and makes decompression dives far more feasible than they are with scuba.

In some situations the extra endurance provided by a rebreather merely shifts the factors limiting the dive from decompression and gas supply to thermal exposure. For instance, in really cold water there may be no good way to provide adequate thermal protection to take advantage of the diving time allowed by a good untethered rebreather on a single dive (*The system's duration could be spread over a multitude of dives; e.g. an entire weekend.—ed.*).

Once decompression is a factor, the optimal gas mix with the right tables makes closed circuit decompression about as efficient as it can get. Having no need for predetermined gas mixes tied to bottom depths makes it easy, at least with fully closed, oxygen-controlled units, to use gases other than nitrogen for the oxygen-diluting gas. Candidates for alternative diluting gases are helium and, for some, neon. While neon is far too expensive for normal open-circuit scuba diving, the gas conservation of a rebreather makes gas costs just a small part of the overall cost when diving with a rebreather. A mixture of helium and nitrogen (with oxygen) would give the advantages of trimix. The U.S. Navy has developed extensive procedures using nitrogen as the inert gas for shallow rebreather dives. But a case can be made that one would be better off using helium for even the shallowest dives.

Another factor in rebreather use—at least the fully closed models—is that they do not make many bubbles. This has obvious military implications, but it can also be important in cave and scientific diving and photography.

Rebreathers also have some negative aspects. First is the cost; current rebreathers range from about $15,000 to $40,000. This is likely to change as the market develops. Not far behind are their complexity, need for maintenance, and the extra training required. Complexity brings with it more places for technical failure and the need for a great deal of additional training. This risk may be compounded by the fact that there is no redundant gas supply on most current units and no spare regulator for a dive partner. In addition, the units are bulky and heavy and if water gets into the breathing loop, the diver can inhale a caustic cocktail, with serious consequences.

Technical Diving Applications

While rebreathers may offer real potential for technical divers, they are not generally available to very many people right now. Of the two types of systems, closed circuit offers the greatest capability for technical applications. Semiclosed rebreathers are simpler and less expensive and might meet the needs of some, but they are sensitive to exercise level and depth, and do not allow the optimal PO2 for decompression purposes.

To date, practically all of the operational experience has been with military rebreathers. This has made it possible for these units to be developed and used extensively without a bailout capability built into the system, since most of their use has been in shallow water where a bailout bottle is not normally needed. In contrast, most technical applications involve diving to depths that makes a carefully planned bailout system essential. This means having enough gas of the right composition to get to the surface or to another gas source under all conditions of operation. This must be taken into account in rebreather operations.

Clearly, considerable work remains before rebreathers can be readily embraced by the sport diving community. But in time, they will undoubtedly become a important tool for the few who can afford the cost and training necessary. In the meantime, closed circuit will remain on the diving frontier: unavailable to most and demanding to those who do gain access to them.

A contributing editor to aquaCorps Journal, Dr. RW Bill Hamilton is a diving physiologist and principal of Hamilton Research Ltd. with over twenty years of decompression management experience in the hyperbaric and aerospace industries. He can be contacted at: 80 Grove St., Tarrytown, NY, 10591 USA, f: 914.631.6134.

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Footnotes:

1. For physiological purposes bars and atmospheres are more or less interchangeable. One atmosphere = 1.013 bars.
2. The kPa, or kilopascal, is a metric pressure unit with great utility. A kPa is 1/100 of a bar - very close to 1/100 atm - and this makes it handy to use. In time, most physiological pressure will use kPa.

AN EARLY History of C2

by
Larry “Harris” Taylor,
Ypisilanti, MI

1680:	Giovanni Borelli conceives of the closed circuit system. He believed that recirculating air through a copper tube cooled by cold sea water would allow impurities to condense.
1726:	Stephen Hale developed a device designed for surviving mine disasters. Helmet contained a flannel liner soaked in sea salt and tarter. This represented first attempt at chemical scrubbing of air supply.
1776:	Freminet designed a “copper kettle” diving dress based on Borelli's theory. Concluded that condensation does not remove impurities; installed a surface supply line to the diver by a mechanical bellows.
1878:	Henry Fleuss of Siebe Gorman receives a patent on an recirculating device using pure oxygen. A year later, he uses this device for first enriched air nitrox dive. The practicality of the Fleuss system is demonstrated in repair of flooded tunnels two years later.
1881:	Achilles Khotinsky & Simon Lake obtain patent on a rebreather that uses barium hydroxide as a chemical scrubber to remove excess carbon dioxide.
1904:	Siebe Gorman obtains patent on Oxylite— a potassium and sodium peroxide mix that liberates oxygen on contact with water.
1905:	A Fleuss apparatus is patented for use in submarine escape.
1912:	Drägerwerk demonstrates a submarine sled equipped with a 2 hour closed circuit supply of oxygen. SCIENTIFIC AMERICAN predicts that this development could be “the advent of a new sport”.
1915:	Oxylite rebreathers are used in the underwater scenes shot for the movie 20,000 Leagues Under The Sea.
WWII:	The Italian's use oxygen rebreathers in military operations against the British in Gibraltar. The British commandos use enriched air nitrox mixtures of 32.5, 40 and 60% O_2. The increased depth capacity of these mixes (compared to pure oxygen) gives the British a distinct military advantage in the defense of Gibraltar. The use of these mixes is classified a state secret and represents one of the well kept secrets of WWII. Lambertsen develops the LARU Lambertsen Amphibious Respiratory Unit) rebreather.

Closed Circuit SYSTEMS REVIEW

by John L Zumrick

Closed circuit systems made their first foray during the second world war where they were used by underwater swimmers to support clandestine bubble-free operations. These first operational units were oxygen rebreathers. Because the divers breathed oxygen, their maximum operating depth was limited to less than 50 fsw (15 msw) and for longer dives to less than 20 fsw (6 msw) to prevent oxygen convulsions.

The general construction of a closed circuit oxygen rebreather is shown in Figure F1. The system contains a breathing circuit consisting of a breathing bag or counterlung, a carbon dioxide absorbent canister, and inhalation and exhalation hoses connected to a mouthpiece. The diver inspires oxygen from a breathing bag to the inhalation hose through a one way valve into the mouthpiece. The divers exhalation is channeled through the exhalation hose where it passes through the carbon dioxide absorbent canister, and is returned to the breathing bag. The carbon dioxide produced by the diver is absorbed in the carbon dioxide absorbent canister via a chemical reaction with materials such as calcium, or lithium hydroxide which is manufactured under various trade names.

Because a portion of the oxygen inspired by the diver is consumed, converted to carbon dioxide and then absorbed by canister materials, the volume of gas in the breathing bag decreases with time. When the breathing bag reaches a small enough volume on inhalation, a trip valve similar to a scuba regulator is opened and oxygen is added to the breathing bag. This serves two functions, it restores oxygen consumed by the diver, and it also maintains adequate breathing bag volume which is reduced by depth changes or gas leaks. An overpressure exhaust valve prevents overexpansion of the breathing bag.

When using an oxygen rebreather it is important to purge the system with oxygen exchanging all air in the apparatus, and in the divers lungs, with oxygen. Since nitrogen found in air is not consumed by the diver to an appreciable degree, it can accumulate in the system preventing the breathing bag from collapsing and adding oxygen to the circuit. In this case, the diver would continue to breath a increasingly hypoxic mixture with little symptomatic warning of impending unconsciousness. As a result this system should only be used with oxygen as the supply gas.

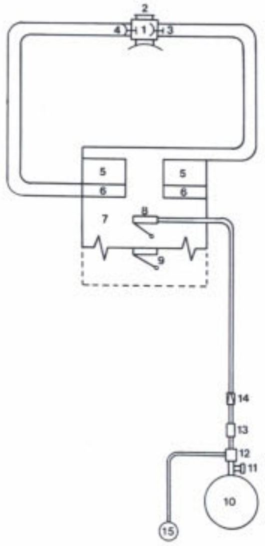
Oxygen rebreathers have evolved since WWII and are still in use primarily by combat swimmers because of their small size, simplicity, and bubble free operation. These systems also have applications in scientific and law enforcement diving.

SEMI-CLOSED CIRCUIT SYSTEMS

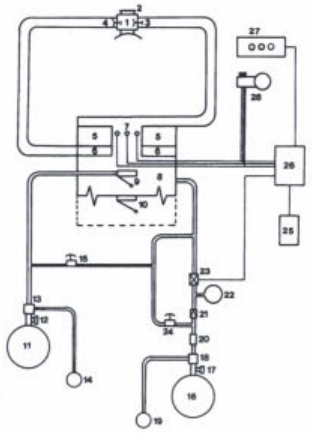
Semiclosed circuit rebreathers were developed somewhat later. Unlike the oxygen rebreathers these apparatus use premixed gas such as nitrox or heliox. The breathing circuit is similar to that of the oxygen rebreather and contains a breathing bag, carbon dioxide absorbent canister, exhalation and inhalation hoses, and a demand valve gas addition system. However, in this design the demand valve gas addition system is used only to make up breathing gas volume lost from leaks or depth changes. To replace the oxygen consumed by the diver, a gas mixture is added to the breathing circuit at a constant mass flow rate independent of depth. The rate is calibrated to adequately replace the oxygen consumed by the diver. A similar volume of gas is then exhausted from the breathing bag through a specially designed exhaust valve.

Since oxygen is added at a constant rate but the diver's oxygen consumption varies with exertion level, the oxygen concentration in the rig varies, being higher when the diver is at rest and lower during heavy exertion. For that reason, the concentration of oxygen in the mixture and the rate of gas addition must be carefully matched to insure that toxic or hypoxic concen-

F1: Oxygen Rebreather



F2: Mixed Gas Rebreather



trations of oxygen will not be encountered during the dive. In addition, the gas mixture selected can only be used over a limited depth range. Thus, while the construction of a semiclosed breathing apparatus is simple, dive planning and rig set up can be complex.

Several years ago at a NAUI IQ, a vendor demonstrated a simple semi-closed system designed for sport divers using air as the supply gas. They clearly understood the design of the apparatus but failed to appreciate how to set one up and calculate the necessary gas flow rate. In this particular unit, they chose a gas flow which resulted in a hypoxic gas mixture when the diver was shallow. This was dramatically demonstrated by a potential customer who became unconscious while using the rig at a demonstration in the hotel pool. Needless to say this rig never made it to market. Because of these types of limitations, the use of semiclosed circuit apparatus has almost been entirely replaced in the US with mixed gas closed circuit breathing systems (*Note that semiclosed circuit technology is used extensively by the British, French and German Navies—ed.*).

CLOSED CIRCUIT SYSTEMS

The breathing circuit of a fully closed circuit mixed gas scuba, figure F2, is almost identical to that of a semi-closed circuit rebreather. The major difference is that oxygen is added by an electronically controlled solenoid valve rather than a pneumatically controlled mixed gas constant flow orifice. When the oxygen partial pressure within the breathing loop drops below a preset level (called the *set point*), an electrically controlled solenoid is activated and oxygen is added to restore the mixture in the breathing loop to its preset level. Because oxygen is the only gas added, there is no excess gas exhaust from the rig, and thus no gas is lost to the sea.

The oxygen sensors and electronics control the partial pressure of oxygen in the rig at a preset level regardless of depth. This has two major implications for dive planning. First, since the percentage of oxygen varies, decompression must be calculated differently. The second consideration relates to nitrogen narcosis. When using air or another nitrox mixture as the make up gas, diving deeper than 66 fsw with a set point of 0.7 atm (used by US Navy divers) results in a greater narcosis than air at the depth. For example, the narcotic effect of using such a rebreather at 198 fsw is equivalent to breathing air at 230 fsw.

Under normal operation no gas should be lost from the rebreather to the water. This high gas efficiency should allow a rig of relative small size, to achieve a long duration that is unaffected by depth. In actual practice this is only partly true. The duration of a closed circuit rebreather is limited by the capacity of the battery to supply power to the electronics, the quantity of make up gas and oxygen carried, and by the duration of the carbon dioxide absorbent canister. Due to advances in electronics, battery power which was often a limiting factor in early designs is seldom a problem today.

The amount of oxygen that must be carried to support diving operations is relatively small. A diver swimming at two knots consumes about 1.5 liters of oxygen each minute. This rate of oxygen consumption is unaffected by depth. Thus, an exercising diver will consume about three cubic feet of oxygen per hour. As a consequence only a small oxygen cylinder is needed while still allowing durations of six hours or greater provided precautions are taken to avoid unanticipated gas loss.

In routine use, diluent or make up gas volume can prove to be a significant limiting factor in rig duration. Once the make up gas is depleted there is no way to maintain the breathing bag volume to compensate for gas lost through leaks, or as a result of depth changes. As a diver descends make up gas is added to the breathing bag to maintain its volume. When the diver ascends the excess breathing bag volume is vented to sea. Thus a sea-saw type profile can result in the depletion of diluent. In addition, gas is lost in mask clearing and from small gas leaks around the mouthpiece. The volume of these losses is greater with depth. As a result, careful monitoring of make up gas supply and care used to minimize gas lost in mask clearing and leaks around the mouthpiece are essential when using a closed circuit system.

The most difficult performance parameter to characterize in a rebreather is the duration of the carbon dioxide absorbent canister. Canister duration is dependent on multiple factors such as the rate of carbon dioxide production, water temperature, depth, and the type of absorbent used. Absorbents are available in various porosities and water content, all of which may effect the performance of a canister.

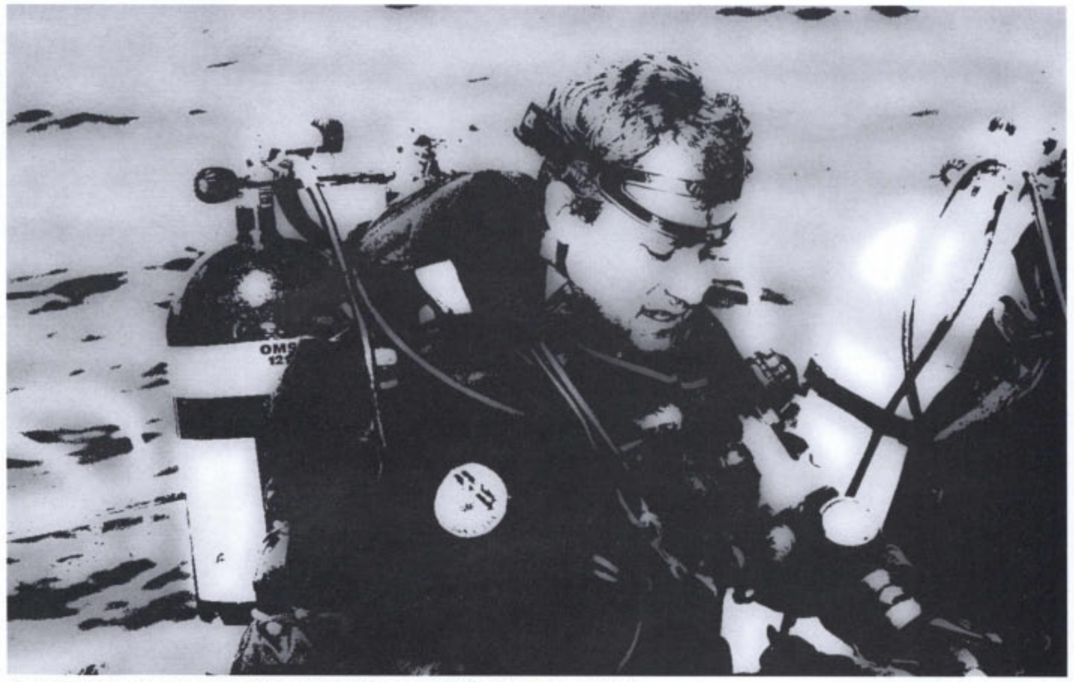
Cold temperatures markedly decreases the chemical activity of an absorber and the duration that it will remove carbon dioxide. Increased gas density as a result of depth and the resulting cooling of the canister will also decrease canister duration. Tests studying the effects of all these factors and canister duration are limited. The work that has been done suggests that canister duration is not a linear function of carbon dioxide production. Thus, doubling exercise rate may reduce the canister duration by more than one half. Consequently careful dive planning is essential particularly during cold, deep, high exertion dives, since these are most likely to tax the canisters capacity.

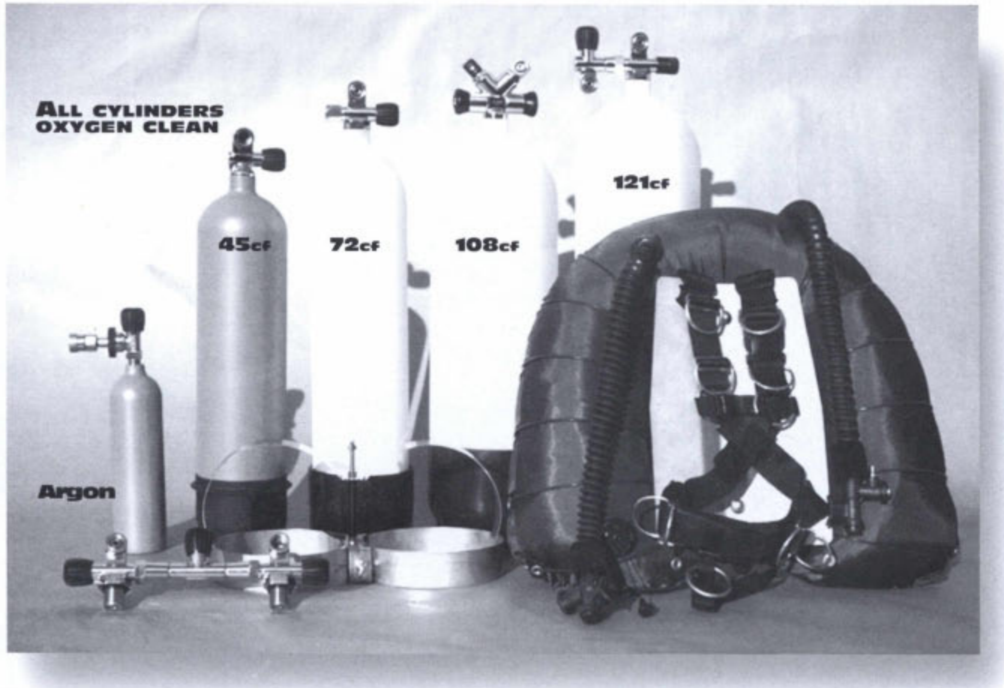
The main hazard in using rebreathers are hypoxia, cerebral oxygen toxicity, and chemical burns. If the oxygen addition system fails, hypoxia and unconsciousness are distinct possibilities. Hypoxia produces minimal symptoms and may not be recognized by the diver prior to unconsciousness. High oxygen levels may occur during rapid descent with an improper diluent gas mixture, going deeper than is safe for a make up gas mixture, or failure of the oxygen solenoid in the open position. This can result in an oxygen toxicity seizure. As a result, it is essential that these rigs have a primary and backup oxygen level display.

If a significant amount of water leaks into the canister the rig may become unuseable. Smaller amounts of water may result in blockage of gas flow through the canister and result in increased breathing resistance. A large leakage may cause a "caustic cocktail", which, if inhaled, will result in chemical burns; though this is rarely a problem in most current models. Since a leak is always a possibility, planning to deal with such problems is necessary.

Today, the cost of closed circuit system is high, but if production expands the price can be expected to decrease. However, in addition to the purchase price, the cost of operation, support equipment, and maintenance must be considered. Consumables alone, including absorbent, oxygen and diluent can run $30-50 per dive, not to mention the cost of regular required maintenance.

Dr. John Zumrick is an active cave diver and practicing anesthesiologist with the US Navy. Prior to serving his residency at Bethesda Naval Hospital, he served as a medical officer at the Navy Experimental Diving Unit at Panama City, Florida. He can be contacted at: 1588 Chain Ferry Way, Orange park, Florida 32073.





Through the *Semi-closed* Door

by Rob Palmer

Semi-closed circuit rebreathers have a long and established history. Used by Hans Hass in the Mediterranean before the Cousteau and Gagnan aqualung, and by most of the world's navies for mine countermeasures and covert operations, their simplicity and efficient use of breathing gas has been largely overlooked by the technical diving community. While closed circuit technology is undoubtedly the most efficient in terms of gas usage and the ability to monitor and adjust the oxygen levels, semi-closed systems come a very respectable second and offer a stepping stone into the re-emerging rebreather technology.

The basic principal of operation for semi-closed and closed circuit systems are very similar. In CCR systems the oxygen and diluent gas are stored separately and mixed under computer control, oxygen being added to replace that which has been metabolically consumed with the diluent providing volumetric makeup. Conversely the SCR system operates by delivering a premixed gas by means of a constant flow regulating device. The gas is delivered at a pre-selected rate independent of depth, a factor responsible for the dramatic improvement in gas usage efficiency over conventional open circuit scuba. The gas enters the breathing loop which consists of a counter lung, breathing hoses, and a chemical carbon dioxide absorbent canister, and is recirculated. As the oxygen content of the recirculating gas is consumed, the deficit is made up by the constant addition of oxygen-rich gas from the regulating device, while the excess gas in the loop is periodically vented from the equipment.

The advantages of SCR systems are their comparatively low cost, simplicity, and gas efficiency when compared to open circuit. Typically gas requirements run about one third of open circuit, depending on depth. The main disadvantage is that they must be used with an appropriate premixed gas suitable for the depth of the intended dive similar to open circuit operations.

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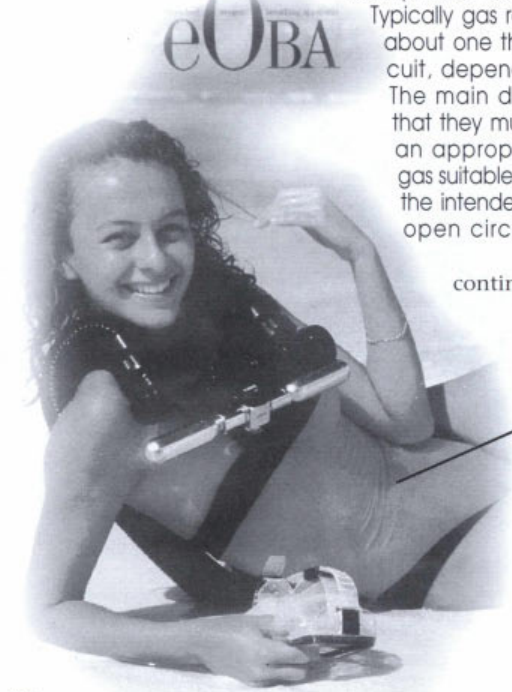

In the event of a catastrophic failure, the fully redundant MK-4R will give the diver 8 hours of gas and enough time to contemplate one of these.

hard ware

New kids on the block...

Huautla expiditioner Noel Sloan with the single configured Cis-Lunar MK-4 rebreather.

The Illustrated MK-4

COBRA

Applications In Law Enforcement

by Greg Brown

The Hillsborough County Sheriff's Office Underwater Recovery Team has been evaluating two Carleton Technologies Inc. Cobra oxygen rebreathers designed for extended duration dives for up to three to four hours at a depth of 25 fsw/8 msw. (*Note that technical divers are recommended to limit oxygen exposures to a maximum PO2 of 1.6 atm or 20 fsw/6 msw—ed.*).

The Cobra was originally designed for military style covert operations—they are silent and bubble-less. Law enforcement agencies that have Emergency Response Teams (SWAT) may be interested in the units for actual tactical operations, but the dive teams will find a use for the units in rescue and recovery operations as well. For example, the Hillsborough Underwater Recovery Team is currently using the Cobra for extended evidence searches. Since the units are streamlined and lightweight, divers experience less fatigue and can continue searches for longer periods of time. As a result, fewer divers are required to complete an operation and it can usually be completed sooner. Oxygen rebreathers have also been used to search for narcotics attached to the hulls of freighters. This is a mission that requires the diver to pay particular attention to depth range since a great many freighters require more than 25 feet of water/8 msw. Most of these operations require open circuit scuba.

Unlike the Dräger LAR V used by the US Navy, the Cobra is mounted on the diver's back, similar to open circuit scuba equipment. This affords the diver with an unobstructed use of his or her arms, adds to the comfort of the unit, and offers less interference during actual operations. The unit weighs only 33 pounds and provides neutral buoyancy throughout the dive. This allows the divers to work without the weight of a normal 80 cubic foot tank and weight belt, thus greatly reducing diver fatigue. Unlike standard scuba with the tank valve and first stage sticking up behind the diver's neck, the Cobra's design is compact, sleek, and less likely to become entangled in aquatic weeds. This also leads to less exertion for the diver when he/she works in heavily weeded areas.

The AGA MKII full face mask has been adapted to the Cobra so that the diver has all the benefits of a full face mask. Combined with wireless communication, the system provides the diver and tender with unbelievable clarity equal to a normal telephone due to the absence of bubble noise.

While the Cobra has distinct advantages there are some problems from a public safety diving perspective that must be addressed. While the Cobra maintains neutral buoyancy, many operations require that the diver be negative. In addition, a public safety diver's BCD is typically rigged to carry tools and equipment. If a diver was

continues on page 23

Special thanks to Tracy Robinette, Divematics, for providing access to his C2 library and to the Waffentauchengruppe

Given limited volume production runs, closed circuit systems could well be regarded as collectible objects d' art. Here are few of the classics.

C2 Classics

AGA-**ACSC** Semiclosed circuit breathing system, non magnetic for use by military.

Biomarine Industries, **CCR-1000**, closed circuit mixed-gas scuba; automatic mixture control: electro-mechanical O$_2$ sensors. Predecessor of the Carleton Technologies **Mk-15/16** used by the US Navy.

Divematics USA, Inc., **Shadow Pac** closed circuit mixed gas electronically controlled rebreather highly redundant with fluidic O$_2$ control. 1976

Dräger **FGG-3** semi-closed system. The current version, the **FGT-3** is used by the German Navy. Used in a John Denver whale special in Hawaii.

GE **Model 1400 (MK-10)** closed cycle underwater system. A spin off of the Mk-10 program for the Navy. Computer controlled with two adjustable O$_2$ set points.

Normalair-Garrett Ltd. **Deep Dive 500** closed circuit deep diving pack - 1979. Used in a James Bond movie.

Oceanic Equipment Corp., **Electrolung,** closed circuit mixed-gas scuba; automatic mixture control: electro-chemical O$_2$ sensor (polarographic).

Old Dominion Research and Development, **Rex,** Closed circuit system with a sonic gas analyzer 1952. Grand daddy of modern closed circuit systems.

Servicios Technicos Marinos Inc., **STM 300** Semiclosed system designed to be sold to the sport diving community, 1977.

Sterling Electronics Inc., Ocean Technology Division, **SS-1000,** closed-circuit mixed-gas scuba; automatic mixture control: cryogenic system, O$_2$ liquid-vapor phase equilibrium regulated by rate of liquid nitrogen refrigerant boil-off. 1967

Westinghouse Electric Corp., Undersea Division, Krasberg Scubarig, **KSR-5,** closed-circuit mixed-gas scuba; automatic mixture control, electro-chemical O$_2$ sensor (gold-cadmium fuel cell).

According to insiders, the USN EX—19, a "next generation" closed circuit system will likely never see the light of day. Reportedly having spent seven years and many millians of dollars on its development, the system is just not going to fly.

Drager will reportedly be releasing the SMS 2000— the German counterpart to Carleton's MK—16 electronic UBA. The system is said to be planned for release in early 1994.

continued from page 20

However, this is not a problem for most technical diving operations where depth, duration and activity are carefully preplanned.

The modular **PRISM** system, developed by engineer Peter Readey is a semi-closed system designed for technical diving applications and offers a low cost upgrade to open circuit diving. The system consists of a user-configurable gas supply, counterlung, hoses and a mouthpiece, a chemical carbon dioxide absorbent canister and finally a means of regulating the gas flow into the breathing loop. The PRISM provides for combinations of various canister and cylinder sizes, integral and separate BCDs, the use of any USN Class A regulator for bailout and a number of extras which allow the system to be adapted and changed to meet the particular diver's and/or project requirements. The system provides about three to five times the gas duration of open circuit scuba depending on depth and can be used with conventional open circuit decompression tables.

As the gas delivery to the SCR is constant, some of the inert gas component has to be eliminated to keep the oxygen partial pressure within the breathing loop reasonably constant. Used gas is therefore vented on a regular basis from the system via the dump valve, hence the name 'semi-closed' circuit. The dump valve can be adjusted to control the amount of gas in the breathing bag at any one time and also to govern the pressure within the system. The flow rate for gas addition must be carefully calculated before the dive, based upon the estimated work load, oxygen consumption, mix and the target PO$_2$; but can be adjusted during the dive. This provides a quick and simple means of dealing with deviation from the dive plan.

According to Readey, "Many people involved with closed circuit technology regard semi-closed systems as a retrograde step. To me it seemed like a logical alternative—a sort of half way house. Semi-closed technology offers appropriately trained and motivated divers a relatively simple means of extending their gas supply as well as protecting their existing equipment investment. Readey estimates that an experienced diver could be trained to use the system in less than a week.

The SIVA unit manufactured by Fullerton Sherwood is used by the Canadian military.

aquaCorps correspondent, Rob Palmer is one of Britain's well known technical divers. Palmer is currently the Special Projects Director of Carmellan Research Ltd, Managing Director of Technical Diving Ltd., and a IANTD instructor. He can be contacted at: Neighbourne Cottage, Neighbourne, Oakhill, Somerset. BA3 5BQ. UK. f: 0749.840.685.

injured and needed to be towed by another diver, it would be very difficult without an inflated BCD. A horse collar style vest may be an option, but it still does not have an air supply other than a CO2 cartridge) or pockets for additional equipment. Orally inflating the horse collar would be difficult with a full face mask, since the unit can not tolerate any water in the system or the dive must be terminated immediately (due to the potential of a 'caustic cocktail'—ed.). An additional problem is providing inflation gas for a dry suit. Although the Cobra utilizes an oxygen cylinder, it is only a 12 cubic foot tank. It may not have sufficient volume for a BCD and dry suit. Fortunately under normal conditions, the dry suit will not require inflation at these depths. *(Note that military and many technical sport divers utilize separate suit inflation bottles for their dry suits. Coupled with a harness/vest BCD these might provide sufficient volume at a 20 fsw/6 msw depth range to drive both the BCD and suit, depending how much buoyancy compensation was needed—ed.)*

The Cobra should be used with a communication system for public safety diving. Although divers may be able to communicate with line signals, there may be situations when there are no physical ties (e.g. lines), such as using a grid to search for small objects. During these situations, the shore personnel and safety diver will not have any idea if everything is going well or if the diver is in distress. Due to the bubble-less operation, there is no indication that divers are in the water. This is difficult for surface personnel to comprehend and leads to increased anxiety unless there is some form of communication with the divers.

The Cobra and other closed circuit systems, offer significant potential for public safety diving. As market competition increases the cost of these units(about US$4000 plus) should drop, making them more affordable. **In the future, you can expect to see an increased number of rebreathers showing up in the public safety diving community. With proper training and modifications they can be a real asset to the team.**

Lieutenant Greg Brown heads the Hillsborough County Sheriff's Office Underwater Recovery Team. Diving since 1977, Brown, a Public Safety Scuba Instructor received his Bachelors Degree in Business Management and Criminology at the University of Tampa and is the recipient of the Sheriff's Office Distinguished Service Award. He can be contacted at: Hillsborough County Sheriff's Office 2008 8th Ave, Tampa FL 33605 USA.

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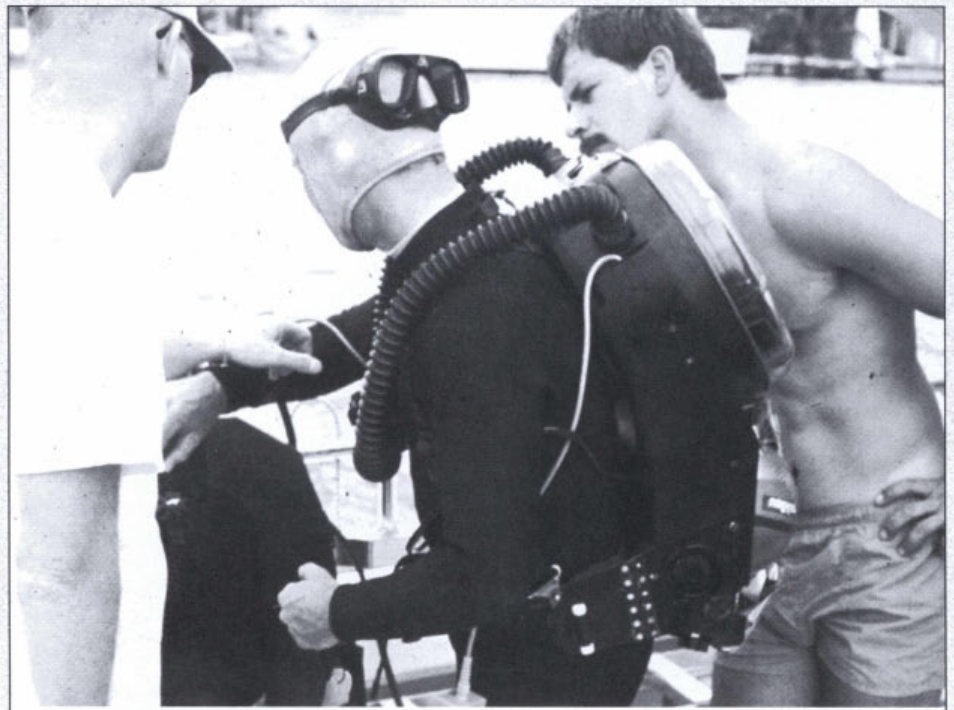


BAILOUT

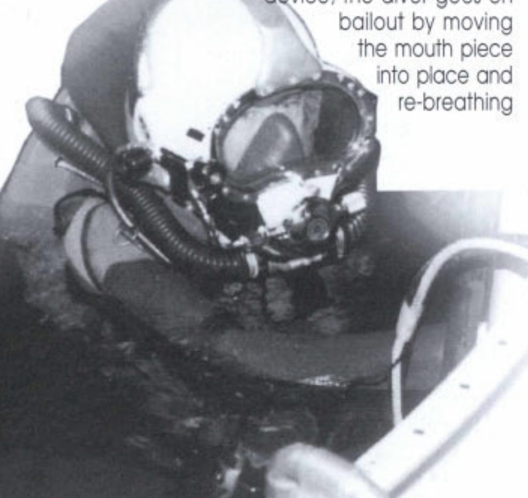
by John P. O'Connor

Over the last few years work has gone into improving commercial bail-out capability in the North Sea. These efforts have been motivated in part by the Norwegian Petroleum Directorate (NPD) regulations and the recognized need to improve the working divers gear, specifically helmets and **bailout systems**.

Two projects were funded to develop diving gear that would meet the NPD regulations for capability to 400-500 msw/1302-1628 fsw range. One group, led by British Petroleum Norway (BP), focused on the Arawak 5, developed by Reimers Engineering, as a starting point. Building on the development efforts of Mr. W. J. O'Neill, BP set out to meet the NPD requirements.

To develop a bailout system that would support a diver for a minimum of 10 minutes at 500 msw/1628 fsw, O'Neill began with a simple concept—**the canister in a hat**—a stainless steel CO_2 canister designed to fit inside the helmet shell with a fold away mouthpiece.

If a diver's primary gas supply is interrupted using this device, the diver goes on bailout by moving the mouth piece into place and re-breathing the gas in the hat. This is accomplished by operating a lever located on the outside of the helmet. Check valves in the mouth piece and canister insure that the gas is passed thru the canister for CO_2 removal. The helmets neck dam provides the necessary compliant valve to act as a counterlung and diver-carried gas bottles supply metabolic and volume make-up gas.



The prototype **canister in the hat** was first tested at Reimers in 1991 by Mr. Melvin Kvamme, a norwegian diver on loan for the project. After swim testing the rig with promising results and further engineering work, Reimers was able to confirm the viability of this innovative design.

Testing showed an added benefit of the rig was the exothermic reaction of the absorbent material and CO_2. While on bailout, a substantial amount of heat is generated in the canister, enough to be felt through the helmet shell—a real plus when diving in cold water. At last report, Reimers called the system, **Dolphin Seven**, and was looking for further field test opportunities.

Founded by nuclear physicist Nils Ottestad in 1984, Ottestad Breathing Systems A/S (OBS), has also been an active player in breathing technology development. In 1987, OBS began work on a new closed circuit system, the **UBA 90-400**. One of the main objectives was to incorporate a pneumatically assisted counterlung in a bailout system. The counterlung is made of a stainless steel box with two flexible sides. A pneumatic actuator provides mechanical assistance to breathing by reciprocating these sides, thereby alternately compressing and expanding the counterlung. Out with the bad air, in with the good.

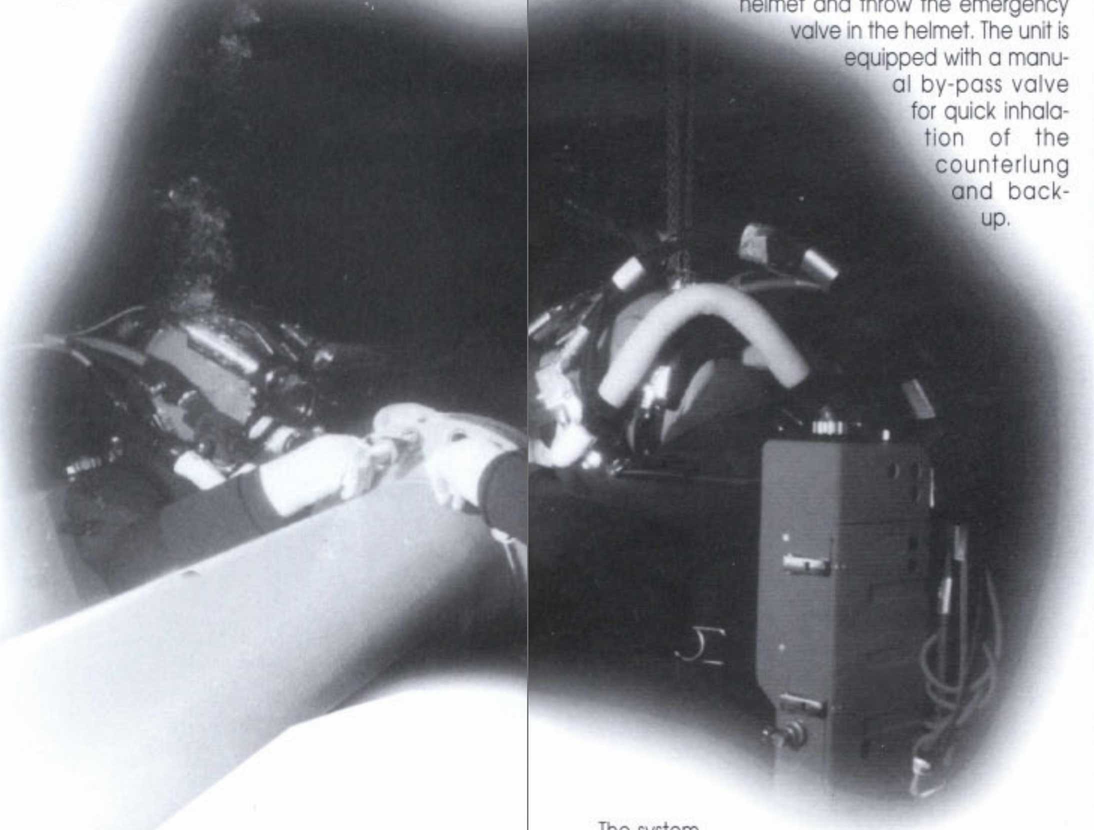
Previously the OBS **UBA 90-400** has been successfully dived to 180 msw (586 fsw) and unmanned (sic) tested to 450 msw/1465 fsw. Earlier this year, OBS performed human bailout duration tests to 200 msw/651 fsw for 39 minutes, and to 450 msw for durations up to 13 minutes, at the National Hyperbaric Center in Aberdeen, Scotland. The dive evaluation was extremely positive—no small feat when dealing with deep-sea divers.

The system offers a low work of breathing, performance virtually unaffected by the divers orientation in the water and excellent ergonomics—**it fits through the trunk of a diving bell**.

Rockwater A/S, a diving contractor based in Stavanger, Norway has taken delivery of OBS's first production run, four **UBA 90-400** sets, and plans to introduce the gear for operational use onboard a diving support vessel (DSV) working in the North Sea in late 1993. Currently the OBS units satisfy all requirements set by the Norwegian Petroleum Directorate for use in the Norwegian sector of the North Sea.

John O'Connor has worked as a commercial diver and dive supervisor both in the US and the North Sea and has an active interest in bailout systems. A graduate of Santa Barbara City College, he can be reached c/o aquaCorps @ POB 4243, Key West, FL 33040 USA f: 305.293.0729.

The BOS



The Comex-Pro **BOS II** (Bail-Out System) is a compact, light weight semi-closed circuit rebreather. It gives the commercial diver the required autonomy for a safe return to the diving bell in case of a primary gas supply failure emergency. The BOS system is connected to the Comex-Pro "Hydralite M3" diving helmet by means of two flexible hoses.

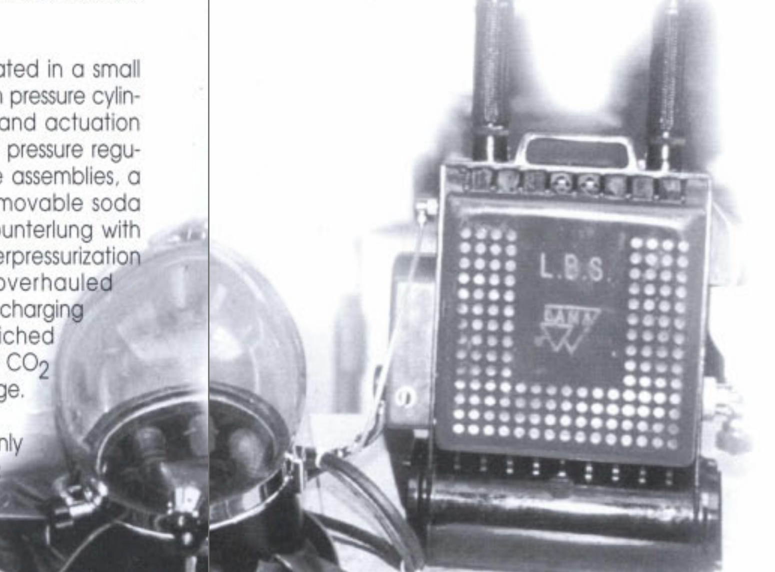
This apparatus uses a premixed gas, and allows emergency breathing for a maximum duration of 15 minutes at 550 msw /1791 fsw. Its endurance can be calculated by means of a microcomputer program, and depends on the depth, oxygen partial pressure, the charging pressure of the cylinders above ambient and the breathing mode selected (from 12 to 75 liters/minute).

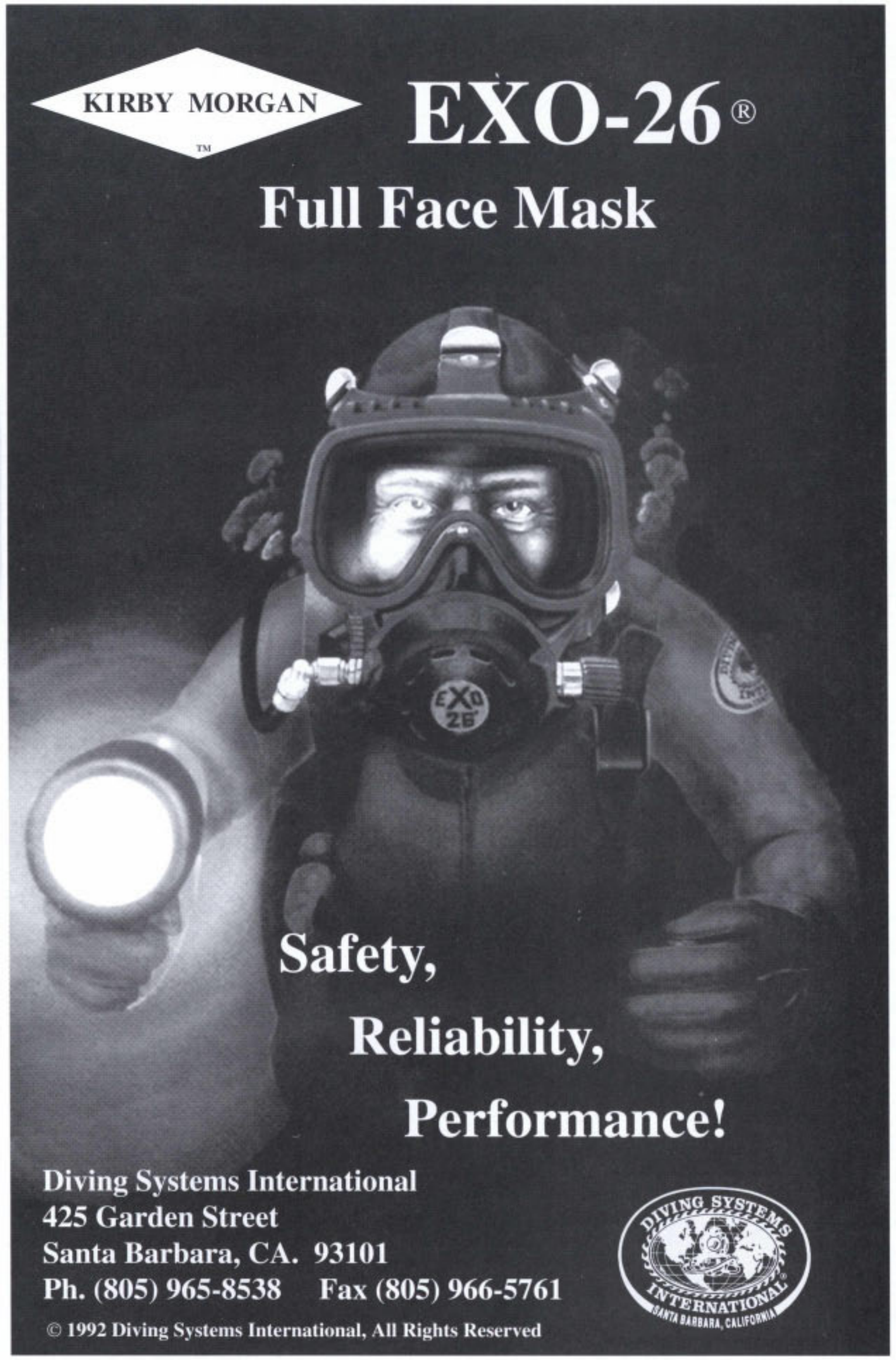
All BOS II components are located in a small housing. These include; two high pressure cylinders equipped with charging and actuation valves, a constant downstream pressure regulator, flow restricter and gauge assemblies, a CO_2 scrubber filled with a removable soda lime cartridge and a single counterlung with inhalation, exhalation and overpressurization valves. The system must be overhauled before each dive in the bell, by charging cylinders with suitable O_2 enriched mixed gas, and by loading the CO_2 scrubber with a reusable cartridge.

Actuation of the BOS II needs only two sequential diver actions: open the high pressure cylinder valve while taking the emergency mouthpiece located in the oral-nasal mask of the M3 helmet and throw the emergency valve in the helmet. The unit is equipped with a manual by-pass valve for quick inhalation of the counterlung and back-up.

The system has been successfully used during very deep dives including the HYDRA VIII dive to 530 msw/1726 fsw on hydreliox (an oxygen-helium-hydrogen mixture—see "Hydrogen Abstract," *aquaCorps Journal* N4, MIX, pg.15) for 30 hours conducted in March, 1988, and the "Aurora 93" project to 450 msw/1466 fsw for 28 hours on heliox at the National Hyperbaric Center of Aberdeen. The equipment is currently in use in Brazil for working dives conducted at more than 300 msw/977 fsw.

Alan Muraccioli is a design engineer in charge of closed circuit systems at Comex-Pro, a division of Stolt Comex Seaways. He can be contacted at: 36, Boulevard des Océans, 13275 Marseille, CEDEX 9-France, f: 33.91.40.72.75





SCANUBA

A Semi-closed System for Nitrox Diving

by Jean Claude Le Pechon
and Yvon Le Masson

At least down to the depth of 50 metres/165 fsw, the large majority of surface supplied diving operations are performed by divers breathing compressed air. At greater depth, air must be replaced with some lighter and less narcotic gas like heliox, providing better breathing efficiency and acceptable performances for the working diver.

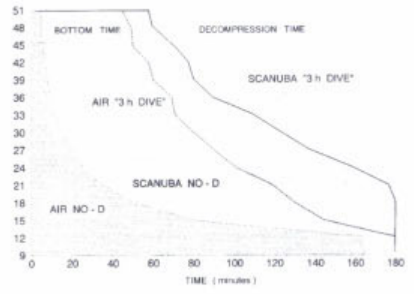
Though enriched air nitrox (EAN) mixtures offer significant physiological benefits over air from a decompression perspective, its use in commercial diving has been limited due to the added operational complexity and expense of specialized mixing and handling equipment. In many cases, the time saving in decompression and decompression quality improvement when carried out on pure oxygen breathing may not match all the expenses associated with the sophisticated operation required (Galerne 1989).

The SCANUBA breathing system has been designed to supply nitrox mixtures to the diver without the operational complexity and expense associated with these operations. As such it represents a significant step forward.

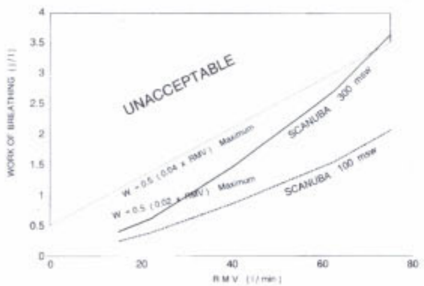
Design Objectives

Self-contained semi-closed circuit systems have been used extensively by navies around the world while tethered units have been used in industry to reclaim gases in deep diving operations. Since the early eighties, the LBS LAMA has been available for deep lock-out dives from diving bells or submersibles and meets industry health and safety requirements (NPD and DOE 1984) for primary gas supply, gas reclamation, thermal control of inspired gases and emergency bail-out at great depth. SCANUBA is a shallow water adaptation of LBS designed for use in surface-supplied enriched air nitrox (EAN) diving, though it's capabilities can be extended for trimix and heliox diving.

The objective of SCANUBA is to deliver a variable breathing mix with a PO_2 of less than but close to 1,6 bar (French legislation 1990). The mixture supplied is of variable FO_2 and optimized to the divers actual depth to provide PO_2 close to 1,6 bar throughout the operation.



F1 : Air and SCANUBA bottom time capabilities



F2: Work of breathing for the back-pack and bubble helmet on heliox (Ransom 1986).

Oxygen Rebreathers: Past and Present

Manufacturers	Model	Manufacturers	Model
AGA (Sweden)	Dum Oxymatic	Fenzy (France)	Oxygers 57 (P068)
Cressi (Italy)	Model 57		(Military type)
Dresco	Model A lung	Mine Safety Appliance	US Navy Mark II
	Model B lung	Ohio Chemical &	
	Model C lung	Manufacturing	Lambertsen Amphibious
	US Navy Mark I		Respiratory Unit
	02 Browne lung	Pirelli (Italy)	Pirelli 50
Dräger (Germany)	DM-20		S-701 Sportsman
	65e-12/G		S-901
	65e-13/G	Scott Aviation	US Navy Mark III Mod 0
	Medi-Nive		Scott-Dräger
	LAR II		US Navy Mark III Mod 1
	LAR III		US Navy IV closed-circuit 02
	LAR V	Siebe Gorman	Admiralty neck salvus ANS
Carleton Technologies	Cobra		Amphibian
Dunlop (UK)	Underwater swimmers		Amphibian Mark IV
	breathing apparatus	US Divers	OXY-NG
Emerson	9-SO-3; US Navy STD.	Westinghouse	Para-min-o-lung
	(of Westinghouse)		
	9-SO-21; double-demand		
	closed-circuit 02 Scubalung		
	9-SO-R1; Mini-O-Lung		
	Us Army diving unit T4		
	(1952 LARU)		

SCANUBA achieves these objectives by using breathing quality compressed air and pure oxygen. A pure oxygen constant mass flow equivalent to 6 Nl/min is provided from surface until the depth of 6 metres/20 feet and then decreases to zero at 50 metres/165 fsw. An air flow, permanently adjusted to the diver's total pressure, increases from zero at 6 metres to approximately 4 l/min at 60 metres. The oxygen carried by the increasing air supply matches almost exactly the decreased pure oxygen mass flow, providing a near constant PO_2 gas at the counter lung. The system delivers pure oxygen during descent and decompression (above 6 metres/ 20 feet) and a variable oxygen enriched mixture (PO2 < 1,6) to 50 metres/165 feet. The air in the system is also used to support emergency open circuit breathing and volume compensation. It's capabilities are shown in Figure F1.

In France total daily immersion time for commercial divers is limited to 3 hours a day by law which can easily be supported by SCANUBA. This duration includes any in-water decompression time when needed according to the Equivalent Air Depth (EAD) decompression methods. SCANUBA can also be used in a surface decompression mode.

System Components

The components of SCANUBA include; a surface unit, gas storage, a back-pack, umbilical and PC compatible software and an optional sensor system. The surface unit is a fully pneumatic gas mixing unit using air and pure oxygen to produce a mixture optimized to the diver's actual depth. The flow is controlled in such a way that PO_2 in the counterlung for a resting diver (VO_2 = 0.5 l/min) is just below 1,6 bar. The surface unit displays the diver's depth, remaining gas supply, alarms, and a predive checklist. The system includes a radio with loud speaker and head set for the diving supervisor. An oxygen analyzer, pressure sensor and a RS 232 computer connection device can be added to provide computer assisted dives. However, SCANUBA is fully functional without the electronic options.

The back-pack, which contains no electronics, is a semi-closed circuit system very similar to the LBS LAMA. The breathing characteristics are shown in Figure F2, and match the DNV and DOE requirements for work of breathing to at least 30 bars for heliox. The system is fully heat insulated and uses thermal sponges. The LBS system has been dived by Comex with no external heat supply to 450 metres/1465 feet using hydreliox and 300 metres in an open sea lock-out from the SAGA submersible in 1990. In these cases, a small cylinder provided bail-out capability for 20 minutes at any depth (In deep bailout mode, the backpack works as a fully closed circuit rebreather with an oxygen delivery equivalent to 2 l/min STPD).

A pneumatic flow control system is incorporated into the back-pack to confirm that the gas produced by the surface mixing unit is actually delivered to the diver. The signal is piped to the diver as a click every second also audible by the supervisor via the telephone link. The bubble helmet is connected via the umbilical to the surface air supply. In addition, there is a diver operated free-flow control that can be activated in case of a low flow alarm, CO2 build-up or accidental system flooding. The back-pack includes a piezoelectric non magnetic microphone/speaker; in the absence of bubbles, communications quality is first class. The umbilical is a three line bundle including; communications,a hyperoxic gas supply which is also used for depth reference and an emergency free flow air supply to the oral-nasal mask.

Optional computer assisted diving is carried out with a PC compatible software which tracks depth, time, mix supply and composition, and pre-recorded threshold values and decompression tables and has several levels of alarms. This can be used to run simulations, run predive checks, monitor and manage actual dive operations and to record an extended log including oxygen tolerance data. The system currently incorporates the the French Ministry of Labour (air/O_2 and heliox) 1992 Tables.

SCANUBA incorporates many safety features as an integral part of it's operation. These include a predive safety check and simulation, gas supply and composition alarms, audible flow control monitoring, a free flow supply line for buoyancy and emergency bailout along with closed circuit bailout capability. In addition, the diver is totally insulated from the water.

CONCLUSION

In summary, SCANUBA is a unique semi-closed system that optimizes a divers breathing mix during all phases of the dive and can supply a variable oxygen enriched mixture using compressed air and pure oxygen. What's more is that the system meets industry breathing performance and heating requirements and offers a complete range of safety features. Though SCANUBA is designed primarily for shallow depths, it can be adapted to meet current industry working depth requirements and for use in bell operations.

Jean-Claude Le Pechon is a consultant serving the diving industry and French Ministry of Labour. A former member of the Cousteau Research Team and Diving Methods & Safety Officer with C.G. Doris, he can be contacted at: HYPERBARIE, 94, rue de Buzenval 75020 PARIS France, f: 1.43.56.20.81. Yves Le Masson is the Président Directeur Général of Laboratories De Mécanique Appliquée, which markets the LBS LAMA system. and can be contacted at: Z.A. Des Meuniers, 7, Rue Des Meuniers 91520 EGLY, France. f: 1.69.26.92.85.

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EXCLUSIVE SDM SCOOP!

Cryogenic Rebreather

First public unveiling of Sub-Marine Systems and their unit.

SDM 1969JUN

By Larry Cushman

Skin Diver On Ice

Though Skin Diver bashing appears to be in vogue in some post-nitrox circles, it should be remembered that SDM played a pivotal role in the development of self-contained diving. Here is one of the "exclusive" scoops that graced their pages 25 years ago. It will be interesting to see how an aquaCorps reads in the year 2019. What kinda mix were they breathing.....?

In July of 1965, Halbert Fischel, a consulting physicist for the government and several aerospace companies, became aware of some of the problems of existing closed circuit technology. Surprised by the primitiveness of existing gear, Fischel identified and began working on the problems of gas mixture control and CO2 removal.

The answers lay buried in the relatively new science of cryogenics—the production and handling of super cold gases. When gases become very cold, they turn to liquids. Fischel's experience with aerospace cryogenics, combined with his physics and diving background led him to consider cryogenic mixed gas control techniques. Oxygen stored in liquid form, although it occupies a fraction of the space required to store the same volume as a gas, has even more important properties useful for controlling gas mixtures.

A year and three months later, the first cryogenic closed circuit mixed gas scuba stood on a laboratory floor in Inglewood, California. The "breadboard" scuba was designed and constructed under Fischel's direction by a team of technicians led by Tony DiChiro, an aerospace test laboratory engineer, and divers Larry Cushman and Dave Joss. In October of 1967 the first prototype unit, Model S-600G, was successfully ocean tested in shallow water at Catalina Island, California. The prototype weighed 104 lbs. and had an expected duration of 8 hours at 600 feet/184 meters. By this time, Fischel had formed Sub-Marine Systems, Inc. (SSI), and began to develop other cryogenic-based life support systems. In April, 1968, the company joined Sterling Electronics, Inc., a manufacturing and electronics distributing company and became its ocean products division.

The SS-1000 is the latest in the SSI's scuba series. When completed, the unit will enable a diver to work at 1000 feet/307 metres for five hours without being forced to handle unwieldy umbilical lines. Conventional fiberglass or metal hel-

continues on page 79

What market insiders are saying about C2

IN THE LOOP

Closed Circuit Intervention

Interview with Stuart Clough,
President, Carmellan Research Ltd.

a.c: When did you get started with rebreathers?

Clough (C):
It was probably the biggest mistake I ever made. Having worked with computer systems, I had gotten involved in marine photographic surveying in the late seventies to early eighties and needed a means of carrying out short deep dives. Open circuit was patently not appropriate. It was fairly obvious that closed circuit offered the solution we needed. I never had any intention of building these damn things.

a.c: Let's talk about control systems. That's been kind of the guts of your conception and design.

C: The ingredients of a rebreather are well established. You need a counterlung, a scrubber, cylinders and valves. All that had been developed. The thing that was missing was a sensible control system to monitor, record, analyze and make decisions and changes during the course of a dive. Computers are ideally designed for that type of application. It was the logical thing.

I came out of the aviation computing side of life where automated flight and process control systems are commonplace. Here was a neat, efficient solution that had never been applied. We couldn't buy what we wanted so we decided to do it ourselves. Several hundred thousand pounds later and ten years later...

a.c: When did you actually crossover and say, "Gee, this should be a product?"

C: That's really very hard to say. There was a lot more to it. When people found out that we were looking at these sorts of things, we got involved in a variety of strange schemes, not the least of which were the typical problems that treasure hunters run into. They use electronic systems for doing a survey, but you don't know whether they've found an oil drum, a piece of pipe or a cannon until they get a camera down there or a diver to take a look. Classifying the returns is the crucial point in any marine survey, and for the sort of medium depth probes down to 100 meters/325 feet, closed circuit rebreathers provides an excellent method for conducting short intervention dives. You can zip down to 300 feet/92 metres for 10 minutes and be up on the deck in no time—a very reasonable thing. At that point the contractor can decide whether or not to commit the funds to put a diver on site or whatever else you need.

a.c: Send in the big toys.

C: That's right. Eventually it occurred to us that we should either desist forthwith or we might turn what we had done into a product. It was our view that we would be better off trying to work with companies that were already in the business rather than trying to reinvent the wheel; hence our associations with Dräger and Oceanic.

a.c: You're nine months to a year away from getting out a product ?

C: Is anything ever finished? [smiles]

a.c: I can see we're not going to get too far on that one. How about markets?

C: **The current market for closed circuit diving systems is most certainly the military but with peace breaking out that market may be in decline.** Obviously people are looking to broaden the scope of this sort of equipment. Most people have seen or heard about the low end systems that Japan has been tinkering with over the last few years. If they are starting to think about closed circuit systems, it probably means the time is right to get something out on the market. Obviously we'd like to see it be one of ours.

a.c: You've done a lot of closed circuit diving, what about systems reliability.

C: The best analogy I can think of is that they are probably something like a vintage car where the requisite amount of tender loving care keeps them going and makes them serviceable. **But you have to lavish a fair amount of TLC on these devices; otherwise they let you down at a surprising rate over the years—some very bizarre occurrences.**

Again, that's the reason we have selected established corporations like Dräger and Oceanic to work with. It's not a cheap solution to get right. You need to be prepared for a few false starts, a few failures, and a few problems during the course of your research and development. The small fries can't tolerate these difficulties.

a.c: On the redundancy side there seems to be two tracks of development. What do you think about Stone's approach—essentially building two rebreathers in one.

C: Suitable for the application he's trying to tackle. A commendable solution to the problem.

a.c: Your approach has been different than that.

C: How many cave divers are in Bill Stone's league and need that level of equipment? I know he's interested in space travel and I think the analogy there is the Lunar Lander. Though it's eminently suitable for the task at hand it isn't suitable for going down the road to the store or for traveling from London to New York. The Cis-Lunar rebreather is going to be damned expensive if they're going to get their investments back on it.

We've adopted a more moderate approach—a basic rebreather that can be adapted to many applications. Sometimes the simplest solution is the most appropriate—a straight reliable rebreather with open circuit bailout made as simple as we possibly can. Certainly in the commercial arena, an umbilical and open-circuit bail-out has been a simple, adequate, sane, sensible way to deal with a diving problem.

a.c: Do you see a potential market in the commercial diving sector?

C: The existing commercial system has a major investment in surface supplied diving and they're not going to change their ways; it doesn't make economic sense for them too. **However, there's a growing demand for inspection, demolition, monitoring, scientific work—short intervention diving—and a need for methods that don't require the same level of logistics. Cost.**

a.c: Isn't that part of the motivation behind one-atmosphere suits, like the Newtsuit? To put a sat diver down to 600 feet/184 metres takes 40 hours with an awful lot of hardware, whereas with the Newtsuit, she's down in 20 minutes with a winch and a couple of support people.

C: Exactly right. Closed circuit systems provide a means to accomplish short economic interventions where you need diver intervention. The way I view it, it's just another tool in the diving locker. It's not the answer to every problem, it's just a piece of equipment that has some very unique treatment. **It is the only piece of kit that will allow you to jump off the side of the boat and go to 40 or 400 meters; you'd have to take an awful long walk to go to 400 meters, but it would give you the working gas.** Operationally it's probably safer from about 10 to 125 meters. That's the range most of our clients are interested in.

a.c: What about regulations?

C: The regulations that have grown up around commercial diving were established for very good reasons. People complain about them, but they grew out of the need to improve the safety of the divers out there. The problem is that regulations are typically slow to adjust to technological and market changes. We do most of our work overseas because here in England, we cannot legally ply our trade over 50 meters/165 feet without a bell which is just not cost effective in many circumstances.

The U.S. Navy uses the MK-16 for small boat operations down to to 300 feet/92 metres as a matter of routine. **And from our own experience, we can say that the equipment is reliable, efficient, and cost-effective for many types of projects in this range. It's not well suited for construction diving. But their are many tasks requiring short dives to have a look, collect samples or check out a situation where it's an ideal tool.**

A mistake a lot of people make is to look at these systems and try to apply them to tasks for which they were not conceived. You wouldn't take your mountain bike down the M-1. There are tools and methods for particular jobs. People who look at rebreathers and say, "Oh, it can't do that" miss the point. You can't do an awful lot of things with them, but for appropriate tasks, they are an efficient piece of equipment just as big SAT systems are an efficient tool for deep tie-ins.

a.c: Maybe that's part of the education process that's going on now.

C: **Rebreathers are not tomorrow animals** [pats his rebreather]. **They aren't just theory.** My problem right now is that the damn things have just come back from a job in the Pacific and ended up getting trashed in customs. At the moment, we have them diving proof but customs-proof is another thing.

Stuart Clough is the founder and principal of Carmellan Research Ltd and has been actively involved in the development of closed circuit technology for over a decade. Clough can be contacted at: CRL, 11 Hillside Close, Ellington, Huntingdon, CAMBS PE18 0AR UK f: 0480.890.946

THE SHADOW KNOWS...

Interview with Tracy Robinette,
President, Divematics

aquaCorps (a.c): Is closed circuit technology the wave of the future?

Robinette: I don't think there is any doubt of that. Everybody wants to have more capability these days; it's a matter of gas logistics. For every liter of gas used on a open circuit rig, a closed circuit uses 0.004 liters.

a.c: Two orders of magnitude difference.

TR: Exactly. Closed circuit is now to the point where it is getting smaller, more safety oriented and redundant which makes it much more viable than it ever has been in the past.

a.c: What will it take for closed circuit technology to become more widespread? What are the key issues or obstacles that need to be addressed?

TR: The biggest thing is training. Closed circuit diving is much more intensive than open circuit diving. And then there's expense—the equipment is more expensive because it is more complex. Complexity also impacts maintenance requirements. You are doing maintenance on an entire system instead of just a regulator and a bottle; two regulators, two bottles, a scrubber assembly, a breathing bag assembly. You've got at least ten different assemblies to consider.

a.c: You mentioned cost and that is obviously a big issue right now. Do you believe it will be possible with volume to reduce user costs to say under $10,000?

TR: Well, **I know that the Carmellan boys are saying that they can produce them for under US$ 5,000 but the only way that they will be able to produce them for that in the States is to get rid of the liability insurance. Your liability insurance alone is going to cost you US$ 5,000 per unit.**

a.c: Is it time for a lawyer joke?

TR: Probably. The other issue is volume. To produce a unit for US$5000 you are going to have to build no less than 1000 sets at a time. That's the only way you're going to achieve that price point.

We've been building closed circuit rebreathers since the mid-70's and the only reason it was viable was because the oil companies had ungodly amounts of money to wave around. The helium costs alone of some of these dives were probably close to $40,000 and so a backpack that costs $20,000 was nothing. It's a write off for a day's work. But even at that price, no one has been clamoring to get rebreathers because of the inherent problems with them.

a.c: What are the diving applications that are going to drive the closed circuit area?

TR: Closed circuit requirements have been primarily dictated by the military—no bubbles, no noise, low magnetic signature. **Covert operations are the driving force in the military community. Outside of the military it's costs and logistics.** If it costs you less money to operate a rig like this than you would normally with open circuit, people are going to go for it.

a.c: Gas costs can be expensive for a big dive.

TR: Closed circuit is the only practical means for bouncing to deep depths without having to have all the logistics associated with surface supplied diving.

a.c: How about semi-closed, do you envision them having a role in all of this.

TR: No.

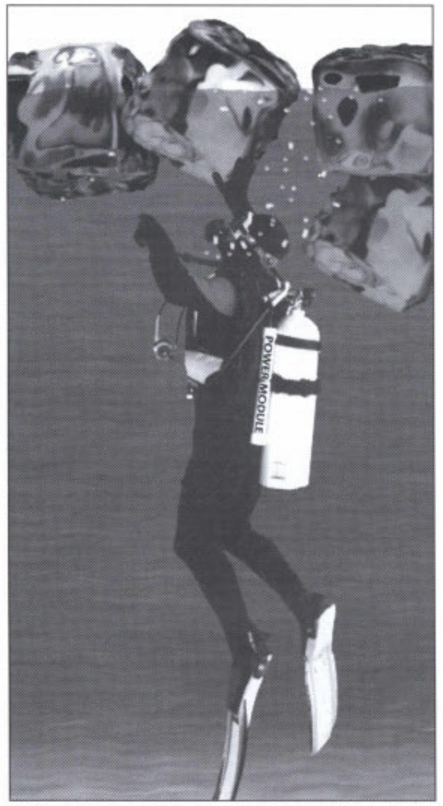
a.c: Why is that?

TR: Semi-closed technology is the stop-gap method that lacks the control of closed circuit. **The reason that you would do a semi-closed system is because you don't want to go to the expense of adding the electronic and sensor package. The problem is that you negate a lot of safety when you go semi-closed instead of closed.** Closed circuit is the way to go. I am convinced of that.

a.c: When will closed circuit become available to the serious diving community?

TR: It still boils back down to liability. **Most of the world, including the insurance companies, view closed circuit as black magic because of the problems it's had in the past. Rebreathers have a bad name.** The technology is there. It really all boils down to liability. Until we get a hold of that, no one is going to want to take a chance with their fortune. It costs a lot of money to develop a system. We are talking a minimum of a quarter of a million dollars.

Let's go back to where the liability really sits as far as the equipment goes. It's square on the manufacturer's shoulders and nobody has asked the manufacturer, well, now do we have liability insurance to cover us for doing this kind of work? The answer is probably no. If you build a piece of closed circuit hardware and you say its good for 1000 feet, you've just bitten off a huge liability. That's the number one priority that must be addressed if we want this technology. I got into closed circuit with blinders, "Oh yeah, I could build this. I could build that." Then I came to the real-



ization—who's covering my butt for this if it doesn't work out. **I'll tell you right up front what I would like to see is a manufacturers cooperative put together to get insurance put together for this type of equipment.**

a.c: That's a $64,000 idea. Let's bring it up at tek.

TR: That's the only way that this is going to work. We might as well band together now because otherwise this thing is going to run into a wall. The only people who won't are the people with foreign corporations. Foreign corporations can typically get insurance for very little money for this type of thing because they are less sued and are less accessible.

a.c: Where do you see the technology going ?

TR: The equipment is going to get smaller and smarter because of computer integration. The original electronically controlled rebreathers were analog devices with a relay that required a lot of power and ran on huge batteries. Those analog devices are gone now. Now you can pretty much put all electronics in a watch-size capsule and you can actually do your pre-programmed decompression and everything else with the pack. I believe this is what Carmellan and Cis-Lunar have right now.

a.c: Stone has a pretty elaborate software system that allows the user to program in decompression and change set points on the fly.

TR: Exactly, everyone is going after the same basic keys to operation. But you are still looking at big backpacks depending on the amount of gas you want to carry and everything else. There are other ways to carry gas and there are other ways to use it. **For example, everyone is focusing on the bite-on mouthpiece—that's definitely not the way to go, there are too many problems with the bite-on mouthpiece.**

a.c: You mean versus a helmet or full face mask?

TR: The first step is a full face mask with a oral-nasal mask that can switch between closed and open circuit for redundancy.

a.c: Open circuit bailout ?

TR: Exactly. It also allows you to plug into a surface supply station which is really nice, especially if you're working off the platform or something. The next stage is a fully enclosed helmet—basically a space suit. You are breathing normally in a gas environment and not having to breathe through a system.

a.c: What do you think about Stone's whole concept of total redundancy?

TR: I don't want to berate him but his system seems overly complex, hard to manage and bulky. The redundancy has to be thought out differently. There's too much focus on mechanical redundancy. He's got multiple hoses, multiple mouthpieces, multiple valves, multiple cylinders, multiple canisters. What is the failure rate of all these components? Why do you have extra components on something that virtually never fails.

a.c: I've often thought that an immediate application for closed circuit is a bailout system for open circuit divers that could give you ten or fifteen minutes independent of depth; enough time to get back to your gas supplies—*a "Spare Air" for the rest of us.* It wouldn't need to be big because if you have a failure, your going home. You just need enough to get back to safety.

TR: Oddly enough, we built one back in the mid-70's. It's called the Shadow 2. I've got two of them here. Basically it's a two hour backpack. A very small device—smaller than a 15 cubic foot cylinder.

a.c: The whole thing?

TR: The biggest problem in making a small unit is the counterlung.

a.c: That's got to take up so much space.

TR: Exactly. The counterlung never changes as far as size, you always have to have the same amount of breathing space. Another thing is that the canister only achieves efficiency after a certain size. All you need to run a canister for 15 minutes is about 1/2 pound of material and you really don't get any exothermic reaction out of it so you really need to pump it up a little bit. A one hour duration bailout is feasible. After that it really gets tough.

Tracy Robinette is the designer of the Shadow Pac which was developed in the early seventies. Robinette has been building custom closed circuit and specialty equipment for the last twenty years and holds a number of patents in this area. He can be contacted at: Divematics, 145 Whiting Ave A, Fullerton, CA 92632 USA f: 714.773.0471.

The Future Is Here

"I think you could say the future is here as far as closed circuit goes. When you think about how much gas someone like Sheck Exley has to carry for a deep mapping push, it's pretty obvious that closed circuit systems will become the scuba of choice for that kind of diving. **All that's needed is a cost a serious technical diver can afford. It probably doesn't have to be that low, either, when you add up what a technical open circuit set costs. Complexity of operation is probably not much of an issue either because this type of diver's willing to deal with it.**

As far as it's use for recreational diving, the costs will have to be close to open circuit and it'll have to be as easy to train for and use. The reliability will have to be about the same as well. "

Drew Richardson, Vice President, PADI

Why not?

"I would suggest there is a very definite place for closed circuit units and there are some areas where the technology is less desirable. Understand that twenty years ago during the Scientist and the Sea Program, an engineer named Fred Parker introduced the first CCR 1000 to the science community. It was a huge success. It was obvious to us then—20 years ago—that closed circuit had a future. **The cost was high but everybody knew it was going to get cheaper and there was obviously going to be additional training requirements but so what.** I would suspect that the scientific community would pick up on this technology very quickly.

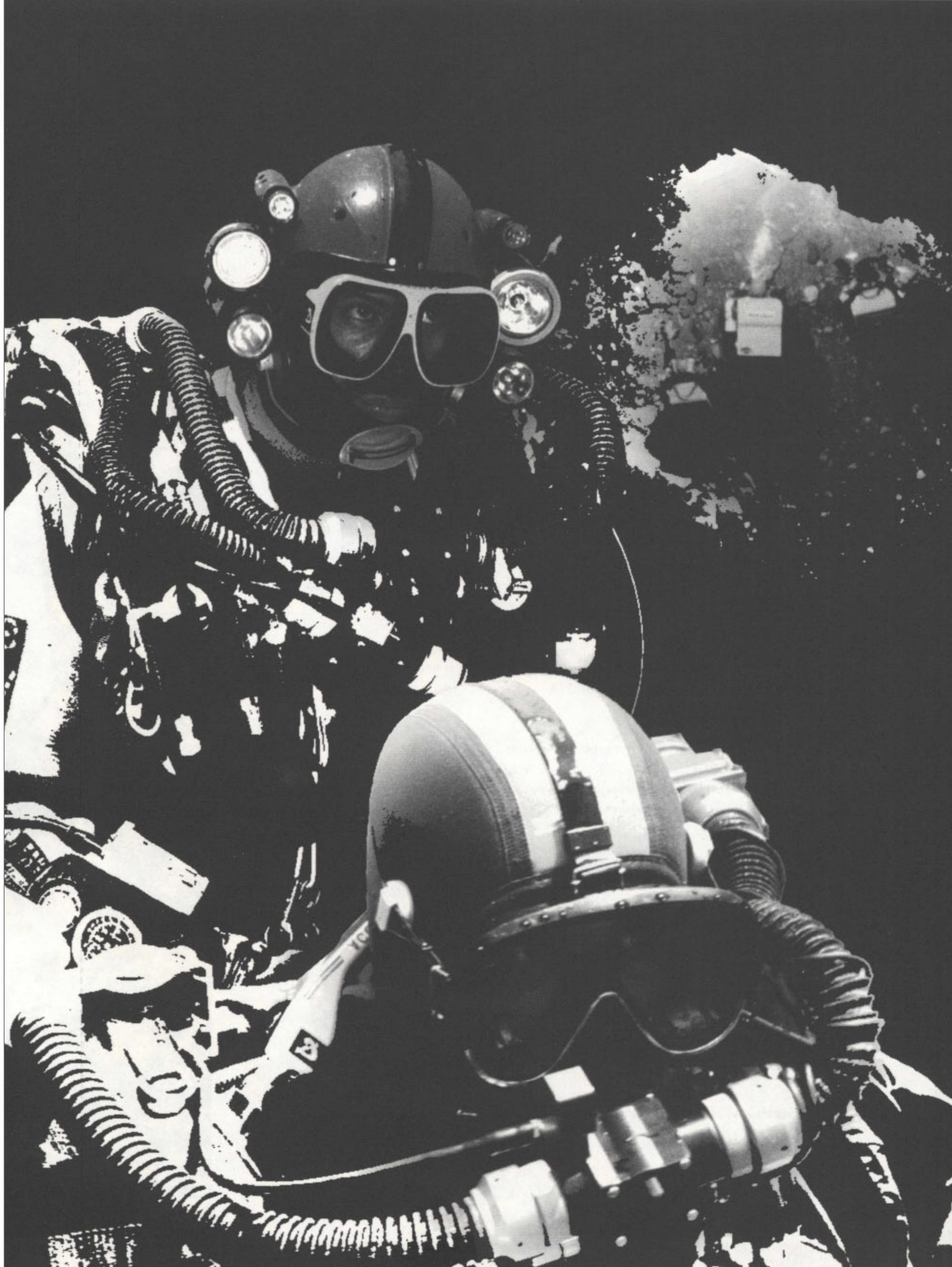
I've been advocating closed circuit for the last twenty years, saying it's going to come, it's gotta come—I mean, how is it that **we don't have it yet?** I do know that Dräger has been working closely with Carmellan Research (*And Oceanic.—ed.*) and that Carleton Technologies has been interested in this community of yours although they have been hiding behind their Department of Defense screen for years saying that they can't. They're interested. They can taste it. **It's going to take a break through by one of these manufacturers—*a paradigm shift*—to make it happen.**

Greg Stanton, Director of Academic Diving,
Florida State University

Militant

"There is no doubt that closed circuit technology is the future of DOD (Dept. of Defense) diving and it's going to continue to evolve. With regard to the non-military diving world, **we are limited by our tort system in the US.** We wouldn't consider selling to

continues on page 67



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DESKTOP

DECOMPRESSION REVIEW 2.0

CONSERVATISM & COMPUTATION

by R.W. Bill Hamilton
and John Crea

DDR 1.0 which ran in aquaCorps N6 Computing, described four decompression software programs that enable divers to plan technical dives for which standard tables are typically not available. 2.0 reviews the conservatism factors used in these programs, presents several comparisons and offers some philosophy about user computation.

Conservatism factors

In Desktop Decompression Review 1.0 we gave some sample decompression times for an air table and a "generic" technical trimix dive. In a way this might not have been a fair comparison because it reported the bare bones table times for each of the programs without any conservatism or "J-factors." There is no reason to expect the default level (that is, with no J-factors) of the programs to be the same. In this section we attempt to explain the mechanism used by each program to increase conservatism, and what J-factors, if any, are recommended by the designer.

DPA

Conservatism is added to the DPA tables by a "gas adjustment." This consists of increasing the inert gas used for calculation by a set percentage. Gas display values are not changed, nor are the oxygen exposure levels. Both He and N_2 can be adjusted independently. A default adjustment of 5% applies to both gases unless changed by the user. The author recommends using at least 5% to depths of about 250 fsw (77 msw), 7.5% to about 400 fsw (123 msw), and 10% beyond that (we don't recommend being very serious about dives to beyond 120 msw, factors or not!). This is a straightforward and well documented method for introducing conservatism. The amount of change of inert gas is specified, but the effect this will have on the table will have to be worked out experimentally by the user. According to the manual an adjustment of 2 to 3% will duplicate the "Bühlmann tables" that are distributed with the Aladin Pro dive computer (ZH-L16C).

There are some additional tricks used by DPA to increase conservatism. The author has observed that Bühlmann's algorithm tends to overemphasize the benefit of oxygen, so the program internally reduces the effective oxygen fraction when oxygen fractions get high. For example, it regards 100% oxygen as if it were actually 80% (this, in fact, is exactly what Ron Nishi did in computing the new DCIEM helium tables; DCIEM, 1992). Another conservatism factor of a slightly different sort is that the program will not allow a diver to ascend (except in the decompression mode) to a depth shallower than half the current depth; this is intended to reduce the effects of "yo-yo" dives.

Dr. X

Dr. X's method of introducing conservatism is by increasing the calculated bottom time. This is done as a logarithmic algorithm for the "deco safety factor" or "adjusted Bühlmann time." How the algorithm operates is not specific, but its results are clear. The program prints an "adjusted Bühlmann time"showing the resulting increase. There are some other operational factors that add to the conservatism of all dives; the descent to the bottom is calculated as "instantaneous," and the time to the first stop is added to the effective bottom time (this of course requires a recursive calculation in the program).

Looking at the effect of Dr. X's adjusted Bühlmann times shows that the implementation of a 100% factor for a dive of 25 min changes ("adjusts") the calculated bottom time to 35.1 min. This makes a dive that had an 89 minute decompression time with a zero safety factor come out to 131 minutes with the 100% safety factor included. This is a substantial modification, and it should make the resulting table a great deal more conservative.

Dr. X discourages repetitive diving. The program allows an "emergency" repetitive dive to be calculated in the usual way by following the decay of gas loading through a surface interval. Dr. X believes that the basic Bühlmann algorithm gives too much credit for oxygen in the breathing mix so does some selective grouping or rounding to help compensate for this in the repetitive calculation. For a repet dive the program uses the maximum depth of either dive, the highest helium fraction of either dive, and the lower oxygen value of either dive for the calculations; an internal exponential function reduces the effective oxygen slightly as a function of the level.

According to the author, the earlier version calculated the adjusted times only on heliox dives except when the adjustment was greater than 100%. Even so, we were unable to get any increases in decompression time for nitrogen-based dives in an earlier version (we are not sure what version it was) for factors up to 300%. The newer Version 4.02 does provide a linear adjustment to the bottom time on nitrogen-based dives for all deco factors greater than 100%. Thus a 150% factor produces a 50% increase in effective bottom time (60 min becomes 90) and a 200% factor doubles the effective bottom time (60 becomes 120).

MiG Plan

MiG Plan uses a straightforward method for conservatism. When a table is made more conservative by introducing "bias," the Bühlmann "b" factor is increased by the percentage of the bias selected. Only three levels of bias or extra conservatism are available, 5, 10, and 15%. The unmodified level is a, and the others are b, c, and d, respectively.

The original version (1.0) also adds conservatism to the oxygen limits as well as bias to the decompression, requiring lower PO_2's as the bias is increased. Thus a calculation at the higher levels of conservatism will not allow pure oxygen to be used at 20 fsw, where the PO_2 is slightly over 1.6 atm. A possible workaround approximation for this is to call for a high-oxygen enriched air mix which would not exceed the limit when oxygen would actually be breathed. It should be possible to adjust the resulting PO_2 so the mix will be allowed. A newer version (1.01) separates the two types of conservatism so that oxygen limits are now handled separately from decompression.

T1: Trimix dive to 250 fsw/77 msw for 25 minutes.
Running Times at End of Stop

	KWC	Mig	DPA	Dr. X	ProPlan
Factor->		"d" 15%	9%N2 9%He	0%	17%
Depth					
250	25	25	25	25	25
140					30
130			26	31	
120			27	33	30
110	29	28	36	31	30
100	31	29	38	32	31
90	33	31	39	33	33
80	34	32	43	35	35
70	37	35	46	39	38
60	41	38	50	42	43
50	46	43	58	48	49
40	57	50	67	55	57
30	75	60	80	67	72
20	89	72	94	79	87
10	116	110	118	114	119
0	116	110	118	114	120

T2: Air dive to 120 fsw/37 msw for 60 minutes.
Running Times at End of Stop

	DCIEM	Mig	DPA	Dr. X	ProPlan	DCAP
Factor->		"d" 15%	11%N2 11%He	0%	17%	11F6
Depth						
120	60	60	60	60	60	60
40	66	65	65	67	67	69
30	74	78	78	82	81	84
20	93	102	107	110	105	120
10	154	158	153	155	152	191
0	154	158	153	155	153	191

MiG also uses an operational means to add conservatism which may cause some confusion. Specifically it adjusts the calculations so that the time listed as "bottom time" is the time from leaving surface to arriving at the first stop. This is done to make the result more conservative, but it is important that the user understand exactly what is going on because it can have the **opposite effect** under some circumstances. Consider a dive that requires 4 min for the diver to ascend from the bottom to the first stop using the programmed rates of travel. If this dive is planned with a 25 min bottom time, the program expects that the diver will leave the bottom so as to arrive at first stop 25 min after leaving surface. However, if the diver uses the **conventional method** of defining bottom time and leaves bottom 25 min after leaving surface the calculated decompression will be **shorter** than intended. This probably accounts fully for the MiG Plan decompression times mentioned in our original article being so short since our calculations were for conventional bottom times and resulted in more extensive exposures.

ProPlanner

Conservatism, called the "Safety Factor" in ProPlanner, is effected by increasing the fraction of inert gas which is operated on by the gas loading algorithm. Each 5% of Safety Factor conservatism added increases the inert gas fraction by 1%. Both helium and nitrogen are affected, in proportion to their original fractions. The Safety Factor can range to 50%, which allows the inert gas to be increased by as much as 10%, adequate for most purposes. The Safety Factor only applies while diving, not while the diver is at the surface. The factors used by Bühlmann in the 1984 book are implemented. For normal dives such as those with enriched air no additional Safety Factor is considered necessary; a Factor of 10% is suggested for trimix dives. The new ProPlanner manual will have more on how to select conservatism factors.

Computation Comparisons

We had hoped to prepare an extensive set of comparisons that would show the necessary J-factors needed to match known tables. This turned out to be a great deal harder to do in a meaningful way than we had anticipated. Because of the numerous subtle differences between the programs, their definitions of bottom time, handling of ascent rates between stops, display of the dive profile as stops only, their use of worst cases, and similar differences we found that direct comparisons are difficult both to make and to interpret. Even so, we tried to find the level of conservatism for each of the programs that would produce a table that gave stop times close to those of a fairly reliable table.

For a trimix dive there is no standard available. For comparison purposes, we have utilized a table that has been used widely enough to establish its reliability and familiarity to a large number of technical divers. It is about as near as we have to a "generic" trimix table. This table was calculated with Hamilton Research's DCAP using the Tonawanda IIa model and Matrix 11F6; it belongs to a set known as the KWC tables. The table selected is for 250 fsw (77 msw) for 25 min using trimix 17/50 (17% oxygen and 50% helium) as a bottom mix, EAN 36 (36% oxygen enriched air) for intermediate mix beginning at 110 fsw, and oxygen (calculated as 90%) from 20 fsw at the end. This table is shown in Table T1, along with the conservatism factors used and the running times for the four programs. Some programs do not present running times (Pro Planner, Dr. X) so we had to reconstruct them from stops, with of course the possibility for error.

Note that for MiG Plan there are only four conservatism choices, the first of which ("a") is the standard table with no extra conservatism, and it took the highest "d" level or 15% to come close to the sample KWC table but we were unable to duplicate its time. Note also that the diver leaves 130 fsw at 26 min, which in effect means that this was not a 25 min dive in the conventional sense (as mentioned above). We might be able to reproduce this table more correctly by doing a dive for a nominal 29 min or so to get a true 25 min dive. The user should be alert to this anomaly.

For DPA, conservatism of both the helium and nitrogen components can be adjusted, which increases considerably the number of possible profiles. Equal values were chosen for our convenience; we used 9% for both helium and nitrogen. It no doubt would have been possible to match the KWC table more closely by trying different combinations for He and N_2; there are a large number of possible combinations and we chose a straightforward one.

Dr. X advises a substantial conservatism factor for this dive, 100%, but we found

In Search Of The Bühlmann Algorithm

by RW Bill Hamilton

Dr. Albert A. Bühlmann worked for many years as an internist at University Hospital, Zürich before retiring. He was a pioneer in deep commercial diving, and has been a leader in practical decompression research and development for some 30 years. His decompressions are considered relatively aggressive by some other researchers, but they are all based on empirical experience. Bühlmann does not claim to be a "modeler" or developer of decompression theory, but he continues to improve his system as experience unfolds.

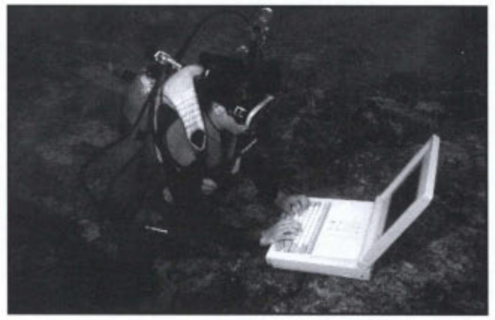
The Bühlmann algorithms—there have been several and they are continually evolving—are "neo-Haldanian" in that they are derived from basic Haldane principles. The heart of Haldane is the concept of parallel compartments (sometimes called "tissues" but they do not correspond to anatomical tissues) that load and unload with gas tension (or partial pressure) according to the exposure and following an exponential pattern. Ascent is limited by the level of calculated gas partial pressure in the compartments. Haldane set his limits as the ratio of gas partial pressure in a compartment to ambient pressure. Bühlmann's algorithm uses a method similar to the one developed by Workman (1965) and refined by Schreiner for multiple gases (1971). This "neo-Haldanian" method sets an ascent limit for each compartment for each depth based on a differential of partial pressures, the difference between compartment gas loading and ambient pressure. The traditional word for these limits is "M-values." The M stands for "maximum." Ascent is halted for a stop as the ascent limit is exceeded, and is resumed when time at the stop has allowed enough gas to unload to enable reaching the next stop, and so on. In Bühlmann's method the maximum allowable loadings are calculated for nitrogen and helium in each compartment in proportion to the relative partial pressures of the two inert gases. Bühlmann's algorithm calculates ascent limits as a specific function of the half times for the compartments, using two parameters "a" and "b," which can be related to traditional M-values. Some conservatism factors are included in Bühlmann's implementation of the algorithm.

The algorithm described in the Bühlmann book is designated ZH-L_{12}; it has 16 compartments, with half times from 1 to 240 min for helium and from 2.65 to 635 min for nitrogen. A newer version, designated ZH-L16 and reported in a later article (Bühlmann, 1988) uses the same half times, and a new book (Bühlmann, 1992) describes the slightly modified ZH-L16A. The latter two references are in German. In ZH-L_{12} the "12" refers to the number of coefficients used (some are used for more than one compartment), not the number of compartments; this is confusing, certainly to us anyway. The basic structure including the use of 16 compartments is the same as ZH-L_{12}, but there are small differences in some of the half-time and coefficient values. The later versions are based on more empirical data. Note that the format for designating the algorithm revisions has been revised as well; they are referenced as ZH-L_{12} and ZH-L16 in the different Bühlmann documents. Two newer models, ZH-L16B and ZH-L16C are mentioned in the book. ZH-L16B was used for the tables in the book (it is slightly more conservative than 16A in the middle compartments) and ZH-L16C was used for the computers supported by the Swiss company Uwatek.

Dr. Bühlmann can be contacted at: Laubholzstrasse 78, CH 8703 Erlenbach, Switzerland.

5% or even no added conservatism (as shown) gave a good match.

For Pro Planner the stop depths in fsw are not all on exact 10 fsw increments; we used the values nearest the stops shown. For depths deeper than 30 fsw the stop depth listed is one fsw less than the conventional depth on even 10 fsw increments; that is, the table shows 39 fsw for the 40 fsw stop. This is due to a "soft" conversion from msw to fsw.



We also tried to set the factors for an air dive. For this we used the DCIEM 120fsw (37 msw)/60min air table with decompression on air. The conservatism and dive times are shown in table T2. Here the programs showed that only a little extra conservatism is needed to match this established table. Included for perspective only is the same dive calculated with DCAP. The times show that the same level of conservatism used in the KWC table leads to a much longer decompression than that of DCIEM. The DCAP ascent matrix (11F6) was developed to deal with the trouble-some longer and deeper air dives (Hamilton, Muren, et al, 1988), but it has also served well for trimix dives.

Can one be too conservative? Maybe. Tables that are longer than they need to be (no one can be quite sure what that is, however) can expose the diver to a longer decompression without a meaningful reduction in probability of DCI and with the added operational problems of a longer dive—having to carry more gas, increased thermal exposures, and perhaps a greater oxygen exposure. Deeper stops are fashionable these days, but this can be overdone. Long profiles need to be weighed against DCI risk for a practical dive plan, as the U.S. Navy, for example, has done in its new tables.

Should you believe the numbers?

The idea of providing a program with which the diver can calculate her own tables is a new concept. This has been criticized in principle from the beginning on the assumption that many users will not have the necessary background to use the programs safely. This criticism has not been unlike that of diver-carried dive computers (DCs) in their early days, but DCI seem to be surviving and working well.

Dr. Brian Hills, a prominent and highly creative authority in diving physiology, once warned those researchers doing decompression computations of the dangers of **computer narcosis.** This is a phenomenon which seems to grip people when they first come to the realization that they have the power to calculate their own decompression tables. The disease has been around for some time now, but with all these programs available the conditions are now right for it to become an epidemic. **The main symptom is that the victim begins to believe the numbers.** That is, calculations are taken literally, compartments and gas loadings assume a high level of reality, and the user may be tempted to take action on the basis of the numbers without recourse to good judgement. **Users are warned that this situation should be approached with caution.**

> One important point might be made about the choice of the Bühlmann algorithm for these programs. It was not necessarily chosen because it is the best algorithm for this application (although it could be) but rather because it is established and available in published form.

What dangers do these programs present? Probably very little to the careful user. Are they really different from a big book of tables? Tables, too, can be misused. The prominent problems of technical diving today seem to be matters of operations and judgement, not so much of decompression illness (DCI) as a result of table quality. Operational problems can kill, but an unreliable decompression table (one that is moderately unreliable) is most likely to result in the inconvenience and annoyance of a treatment but little serious risk (provided proper treatment is initiated promptly if DCI does occur). If these programs enable more divers to use helium based mixtures—such as trimix—instead of air then their net result should be beneficial.

Recreational divers traditionally try to milk all the time they can out of a table, doing anything they can get away with and still "legally" follow the table. That attitude will get someone in trouble with desktop decompression software.

The user needs to look carefully at what has been generated and compare it with past experience of the same type. This applies especially to oxygen limits; the user is expected to have enough of a feeling for what is risky to be uncomfortable with a given excessive exposure, even without the program's warnings. If a dive is coming up on which there is no relevant experience to draw from, the diver should rethink the whole idea, or get help from someone who has the experience. Most of the planner programs say something to this effect in their instructions.

There are several analogies between these planning programs and dive computers. Many of the DCI use one or more of Bühlmann's algorithms, either developed by Bühlmann himself, or from the 1984 book and its more recent modifications (see sidebox). Dive computers are felt to be inadequate for closely spaced deep repetitive dives, yo-yo dives, and reverse order repetitive dives (where a deep dive closely follows a shallower one); the Bühlmann-based planners are likely to have the same inadequacies. Although users are warned and some restrictions apply, in general the planning programs allow these types of dives to be calculated.

Another set of limitations to consider are the maximum depths and times for which programs of this sort should be used for self-contained diving. As depth increases several risk factors begin to accelerate. First, operational considerations such as distance from the surface, gas supply, gas consumption rates, precision of gas analysis, etc., get more demanding, making the operation increasingly more difficult to carry out safely. Second, the quality or reliability of the decompression is reduced as the total decompression time increases. Accordingly, we strongly recommend an appropriate maximum depth beyond which these programs cannot be used with confidence. If the program is refined and checked, J-factors validated, and the user is highly qualified both to use the program and to make the dives, **a limit of about 300 or 325 fsw/ 100 msw might be reasonable for well planned and supported self-contained, open-circuit, trimix dives. Regarding times, dives beyond about one-half hour in the 200-250 fsw/60-80 range and about 15 min near 300 fsw/90 msw should be approached with great caution, as well as longer dives of more than an hour in the 150 fsw/45 msw range.** The deeper and longer the dive, the more urgent is the need to have recompression capability (i.e., a chamber) available at the dive site.

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DDR 1.0: AUTHOR'S FEEDBACK

DPA

We incorrectly stated that DPA's algorithm was the Bühlmann ZH-L16. The algorithm is based on the ZH-L$_{12}$ model from the 1984 book. The new version of DPA which is scheduled to be ready by 94JAN will use the ZH-L16. Metric units will also be included. Ascent rate was incorrectly listed as "instantaneous;." DPA ascent rates are fixed at 30 fsw/min and are not adjustable by the user. The comment in the chart that telephone support is discouraged is backwards; it is encouraged.

Calculations of flying after diving can be done although there is no function dedicated to that. The user sets depth for the "surface" as a stop at something like 0.1 fsw, with the decompression target as the required altitude (which should be 8000 feet for commercial airlines). DPA will then hold the diver at the artificial "surface" until clear to the altitude; there is a provision for coding in feet of altitude. For diving at altitude the user offsets the surface to the pressure of the mountain lake as a negative depth. Normal dives are considered to be valid to 1000 feet altitude, a reasonable assumption.

Dr. X

Version 4.02, dated 93Jun, appears to be a substantially improved version of Dr. X over the one reported on last time (which was 3.54). Some improvements include improved decompression with enriched air, incorporating conservatism factors (in the early version only heliox dives used the "deco safety factor"), multilevel dives with multiple mixes, emergency repetitive dives for all mixes, diving at altitude to 10,000 feet elevation, adjustment for travel mixes on descent, user controlled descent rate, equivalent narcosis depth, relative flow in density calculations, more warnings, more tank options, and an improved user interface. Version 4.04 also includes a metric switch, with which dives are "soft" converted to metric units. That is, the dive is calculated in fsw but displayed in msw; conversion is thus 3.33 fsw per msw (aquaCorps uses 3.2568 fsw per msw as per discussion in Corps letters, aquaCorps Journal N5, BENT.). The altitude calculations use the Cross Corrections algorithm, which means it should give a very conservative hypothetical depth as a function of the altitude of the dive.

MiG Plan

We incorrectly stated that MiG Plan was a ZH-L16. It uses the Bühlmann ZH-L$_{12}$. MiG Plan also offers a 12-compartment model derived from Huggins (1987) and using the method for handling different inert gases proposed by Schreiner and Kelley (1971). The authors of the MiG Plan take issue with references to "their" algorithm. They take credit for the program which makes the algorithm available, but they do not consider the algorithm theirs in any way. Likewise, when asked for their recommendations on the degree of conservatism to use under different circumstances they opt out. That is, they do not consider that this type of choice is within their expertise and they do not offer advice of that sort; they pass this responsibility off to those offering instruction in technical diving technique. (This seems to us to be a sensible and honest position, but we have some reservations on whether many instructors who teach technical diving have the expertise to do this either—RWH). MiG Plan offers the possibility of calculating a table for diving at altitude, using the same methods as described by Bühlmann. The user has to request a free disk upgrade to get this capability. Some cautions are in order for altitude calculations, including particularly that it is necessary to have a depth gauge that can be zeroed at the surface of the lake.

ProPlanner

A new version of ProPlanner is reportedly in the works, which will incorporate several useful improvements, some in response to our suggestions. Both msw and fsw will be standard units; we are not sure how this is to be done, but we hope it will be a "hard" conversion such that calculations are made in the units used and the increments are thus appropriate (this is a little ragged in the current version). Elapsed time will be shown on the table, as well as file name and date. It may be possible to save current gas loadings, to allow further dives to be appended. The ProPlanner authors are reluctant to give the user the ability to edit the output, since by implication errors can be introduced, a concern shared by all (but we recommend output to a file). Perhaps a more meaningful change along these lines will be a limit of 200 msw or less on calculations for rebreathers and 100 msw on open-circuit trimix. Gas mixing and logistics calculations will be added.

GAS PLANNING

Several of these programs provide gas planning functions, both for consumption during a dive and for use in preparing mixes and in topping off partially used tanks of mix. We did not review these functions in detail, and users are advised to follow through with each type of gas mix calculation manually with a hand calculator as a check on both the program and whether it is being used correctly before relying on the program alone.0

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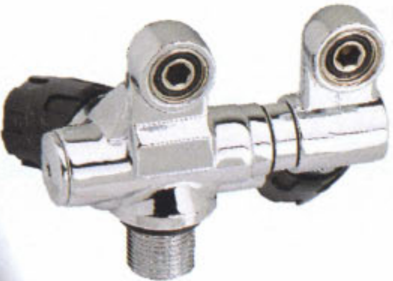

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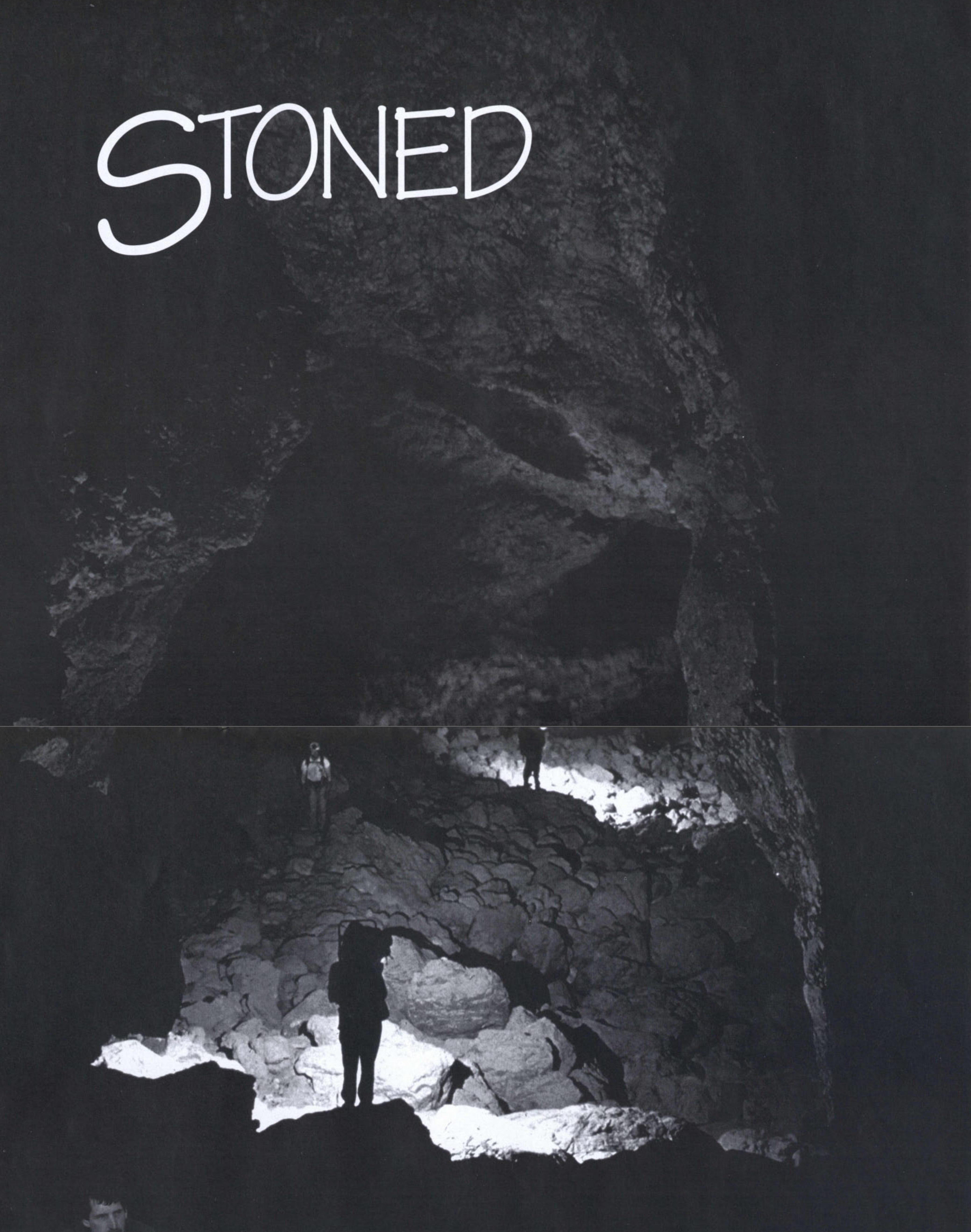

Having descended on the technical diving world nearly ten years ago, caver and engineer, Bill Stone, 41, has blazed a trail that has left many people reeling in amazement—definitely mind expanding stuff.

by Michael Menduno

Known as the Barnum & Bailey of diving to his friends and cohorts, his larger-than-life productions have captured the imagination of a generation of divers and served a pivotal role in the development of self-contained diving. During his milestone Wakulla Springs Project in 1987, Stone and his team explored over 2.3 miles of underwater passage, logging more than 450 dives at depths ranging from 260 to 320 feet (80-98 meters) and in the process, helped pioneer the basic tools of modern technical diving; open circuit mix diving, long range DPV's, a variable-depth decompression habitat or "microbell," and Stone's first rebreather. All this before mix diving even made it to the closet. Take another breath.

But Wakulla was just a stepping stone in Stone's grand scheme: bottoming out the Huautla plateau system in Central Mexico—his consuming passion for more than 20 years. Working their way through twisted miles of dry cave, subterranean rivers, waterfalls and sumps, Stone and company have descended to over 1350 metres in an attempt to connect the San Agustin entrance located on top of the plateau to the spring that flows from it's base. By their estimate the team has another 350 metres to go to reach their goal which would make Huautla the second deepest cave in the world. Their final push is scheduled for February of this year.

When he's not dangling 200 feet in the air on a practice line, or pumping out "counterlung simulations" on the Cray-1 computer that he has convenient access to at his 50 hour a week real job at the National Institute for Standards and Technology, Stone is busy chasing down funding for his company, Cis-Lunar Development Labs, which will eventually manufacture his closed circuit rebreather. And if that were not enough, he still finds time to dream about "what he really wants to do when he grows up." A subject he's a bit hesitant to talk about for fear of raising too many eyebrows.

The term "space cadet," takes on a new dimension when the moniker is applied to Bill Stone. Not bound by conventional terrestrial constraints, Stone has set his sights high—about 208,000 miles above the earth to be exact—one of the five Lagrangian points that represents a stable gravitational point between the earth and its moon. His long term goal is to apply the technology that he and his team have developed to put a privately funded team into orbit. Far fetched for mere mortals to be sure, but judging from Stone's verve, imagination and drive, it's a proposition that just might fly.

Perhaps the power of men like Stone lies in their ability to dare us to greatness—the power to look out into that immensity that surrounds us and ask, "Why not?" Clearly, Stone has made his decision to touch the frontier, and in doing so, allow each of us to touch it as well, if only vicariously. In the long run perhaps this will be judged as his most important contribution.

a.c: We've been talking about doing this interview since 1990. It's been a long time in coming.

Stone (S): Maybe now the time is right. You're an established editor and I think I know how to build a rebreather. I suppose you've heard the classic about a couple of people who came in last year and someone asked them, "Oh, are you going closed-circuit today?" and they said, "No, we're going bubbling."

a.c: Bubblers, a new term.

S: The new term for open-circuit.

a.c: You've been working on it for...

S: Nine years.

a.c: Nine years? I can relate to that. It takes a lot of work to create something.

S: Fifteen years of hard work is equal to an overnight success.

a.c: I'm sure that there are many people out there who think that you are probably crazy or stoned to do some of the things you're trying to do.

S: The attraction is exploration and it's brought a whole team of people together. They want to use this device to do something that's really going to be provocative if you will, for lack of a better word.

a.c: Capture people's imagination?

S: Including your own. If you're not doing something that's out on the edge, and by that I don't mean dangerous, I mean something that captures you're imagination, well? It's like.. My God. Here is a challenge that heretofore has never been done, that has never been contemplated and we just might be able to pull it off. That's not going to happen until we know we can do it safely—that's why it's taking us so long. I don't want to bite the big one just to say that I used a rebreather.

a.c: Your headed for Huautla.

S: We're on for February 2, the kick-off date. In fact a lot of the crew is going to end up arriving over here in the middle of January for two weeks of chip-soldering and software burning. The software is always in a state of flux. Every year for the last three years it's happened this way. Push, push, push and finally you get the software burned. It all happens two days before you're supposed to leave town and everybody's sitting up at 1:00 in the morning with micro-fine soldering irons putting chips on the fucking computer boards.

a.c: Just-in-time expeditioning. Does that mean you're funded?

S: We're 90% there. The hard road has been taken care of. We've got the rigs in an operational state, we've got all the transportation arranged and the political clearances in Mexico are being taken care of right now. In fact, we've got negotiations going on with the Governor of Oaxaca all the way up through the Foreign Affairs office in Mexico City.

a.c: You need clearances?

S: With a project of this magnitude, you do. What ends up happening is that you drive down to the border with a caravan of six trucks filled with gear. The border guards

"In today's world of robotics and computers, many researchers feel that effective exploration can be best accomplished through the use of sophisticated "intelligent" mechanical surrogates that will carry out science through telepresence. What then of human exploration? Does knowledge in itself (gained by mechanical scouts) constitute satisfaction and motivation for living? Or must we touch the frontier ourselves?"

William C. Stone, Ph.D
Wakulla Springs Project, 1989

pull open the sliding door on the back of the truck and go, "Whoa" and immediately they think they've got an opportunity. To avoid that kind of stuff we get prearranged clearances.

a.c: You've been going at Huautla for a long time.

S: I started caving in high school in 1967. I heard about Huautla a year later. The story goes back to 1964 when Bill Russell at the University of Texas in Austin was looking at military topo maps for Mexico hoping to find the deepest cave in the world. You can do a lot of the analysis with maps and when you think it adds up to something deep you get in your truck and go and take a look. That's what he was doing when he found Huautla.

Four years later in '68, a joint Canadian-American expedition set the Western Hemisphere depth record, which was like 600 metres (1960 linear feet). In those days that was just phenomenal and everyone including myself was just blown away. "My God, they're that deep underground." To give you an idea of how things have changed, we're now shooting for 1700 metres (5575 feet).

a.c: Seventeen hundred metres will put you at your final camp?

S: No, that would be the entire descent from the highest entrance to the springs—we haven't made that connection yet. That's what this whole expedition is about. We've reached 1353 metres from the highest entrance to the sump. That's our dive site.

a.c: When did you finally make it there?

S: I found myself in Austin which was the hotbed of expedition caving in the Western Hemisphere in the seventies. People came from everywhere to that town to organize, head for Mexico and go deep. That was the driving force in the seventies; depth, depth, depth. When we got to Huautla in '76, we found an abundance. They had missed everything in '68 and the earlier expeditions and of course the gear and equipment had all changed. Looking back, it was a little like the argument for [Sir Edmund] Hillary and Norgay—some people say, "Well, it's not that big a deal to put 60 people on the summit now on a good day in May." That didn't make it any easier the first time.

a.c: The learning curve.

S: We sent our first three-month expedition down there in 1979 and it felt like we were going to the dark side of the moon. We set Camp 2 at a depth of 500 meters, moved on from there to Camp 3 at 800 meters. That was our game for the longest time: depth, depth, depth. We were underground for 17 days.

a.c: Seventeen days?

S: A classic Huautla story. We went down there planning a 12 day trip. We left on March 5th. Nobody had Rolexes with dates and that kind of stuff; we had Mickey Mouse watches. It was like, "What time is it?" "It's 12." Great, is that a.m. or p.m? Well, I'll just write that down as 12. We went through 12 motions of having breakfast and dinner, and we realized that we would have to bail because we were out of food. We got back to the surface and there was a note on the table dated March 22nd and we said, "Naaahhh. We couldn't have walked five and a half days." Finally a school teacher comes over and says, Where have you guys been?"

a.c: Underground.

S: We lost five and a half days of our lives there. Everything was dilated. We were up sometimes for 40 hours, really not even noticing it. If you try to stay up for 40 hours on the surface you'd be trashed. Of course sometimes you come back and sleep for 20 hours without waking up, which again is bizarre. That's all history now that people have date watches; everything is semi-cued to the surface. People prepare their departures so that they return at dawn and have some nice sunshine to dry their clothes off; because they haven't seen much [sun].

a.c: Is that when you started cave diving?

S: Yeah. I was introduced to cave diving in Texas using a single tank and regulator to dive flooded tunnels. Fortunately for me, a fellow by the name of Mike Boone, who happened to be one of the archetypal cave divers in Britain in the sixties, came down, heard what I was doing and said, "Do you do want to survive?" And I said, "Sure." "Well, then get a second set of tanks and wrap them on your hips like this." That's how I learned cave diving, British side mount style, which was an anathema to what was being done in Florida—a whole different ball game. That's what I started using in Mexico.

When we went back down to San Agustin in '79, I had these two tiny little 15-cubic foot buddy tanks. I got about 150 feet into the sump at a depth of about 40 feet and I was looking into this gigantic blue void and went "Whoa. I don't think we're going to make it with these little things." That plagued me for the next two years. God Almighty, this was the deepest point in the system. We were trying to break a world depth record and the only way we were going to get there was to follow this thing down until it turned around.

a.c: Is that when Exley got involved?

S: I wrote to Sheck that next summer and said, "I need to learn about deep diving. Will you take me on?" He said, "Jump on the plane, man."

I went down there and he said, "The method by which you acquire depth is to go through a progressive series of exposures on compressed air." So that's what we did. We went to 40 meters, 50 meters, 60 meters, and our next dive was going to be Eagle's Nest. He pulls out an oxygen bottle which was absolutely alien to me at the time and I said, "What's that for?" He says, "With these, you can go real deep." Man, I was going, "Uh oh, I'm in trouble."

The next day we go blitzing down Eagle's Nest, and I'd learned on the course of the previous dives that if I paid attention to what I was doing, as opposed to just looking at the instrumentation, the better off I was. That was the game, that mental concentration, knowing exactly where you were and how impaired you were. Guys like Tom Morris and Sheck Exley would come back from a dive and say, "That was great." And we'd go, "Right", I 'd look at them and say, "You were buzzed down there, weren't you?" "You bet your sweet ass I was."

That's exactly what happened to me. We got down to 240 feet (74 meters) on the way to the Super Dome or something and Exley gives me the thumbs-up and OK. I turn around and the old delayed psycho-motor response syndrome that you get with narcosis was taking its toll and I never bothered to hit my BCD to pull myself back up. At that point I was coasting down at about 200 on the port side of narcosis and hit the mud. Splat. One great stroke and the whole place blacked out to zero visibility and this mushroom cloud that was probably eight feet in diameter engulfed me like a little atom bomb.

Exley and his partner were about 20 feet (6 meters) above me in the tunnel watching with some amusement wondering what the hell I'm doing—*we gotta teach this boy some technique.* Meanwhile I'm going *Oh, jeez, I just lost a guideline* and the old heart starts to pound and I start hyperventilating and the narcosis builds up and all of a sudden I'm on the other side of that little nice edge and I'm going, "Uh oh, I fucked up." Don't quote me on that. Next thing I remember is that vicious little cycle that goes, *"I can't find the line, I screwed up, oh jeez, where's the line? I screwed up. I can't find the line."* And I started hearing this thundering locomotive type echoing of all the bubbles going off and tunnel vision starts setting in and the next thing I know I see this hand coming through the blackness and I go, *I better grab this.* And I grabbed it and Exley pulled me up about 25 feet and maybe 30 or 40 feet back down the tunnel and all of a sudden, Bingo, I snap out of it and I go "Man, what happened?" He signals, "There's the guideline, let's follow it out." Everything goes perfectly from then on and Exley's as cool as a cucumber. We get back up on the surface and he says, "Tried your limit?" I said, "Yeah, I don't think we're going any more than 200 feet when I get to San Agustin." That's where I set my limit. Exley saved my life.

a.c: You've been called the Barnum & Bailey of diving—your projects are like a three ring circus. Talk to me a little about some of the logistics at Huautla.

S: We spent a year finding people who could cave and dive and another year rehearsing all the techniques that we knew we would have to deal with. Transporting camping equipment including freeze-dried food and sleeping bags through underwater tunnels and then planning on setting long-duration camps on the other side. We were the first to ever do that. It was a very intimidating prospect. We didn't know what difficulties we would have.

To give you an idea, we carried 8 tons of equipment on our trip to explore Pena Colorada canyon. We hired 190 Indians to work for three and a half days hauling all our gear down a mile into the canyon with sixty burros and another 50 Indians to chop out a 100 by 50 meter area in the jungle. It was so dense when we got there, we couldn't even put up a tent. We spent three months in that 150 meter canyon diving up toward San Agustin from the bottom. In the process, we ended up pushing through seven underwater tunnels (sumps) with seventy two composite tanks supplied to us by Accurex and Sherwood. The classic siege—*pyramid logistics.*

You start off with seventy two scuba tanks which you haul into the cave to get to the first sump. You use up a dozen to get through to the other side, and then you start hauling them to the next sump. Now you have less tanks so a few people have to drop out. You go through the next sump and trash another dozen tanks out of the plan. And on it goes. We kept doing this until we were left with two support personnel and two divers and four tanks. At that point we were four-and-a-half kilometers into the mountain about twenty-five percent of which was underwater. That was our final dive. We did that three times, hauling all the tanks in, pushing further and further and further each time, then hauling them all back to the compressor and doing it again. The final obstacle was a real nightmare.

We knew were going up because we were at 300 metres deeper in elevation than the bottom of San Agustin, the bottom itself. From the way the geology works we were eventually going to get through to airspace, we had worked all the hydrologic flow calculations. So we had 300 metres of elevation and we were scaling shafts for quite some time. At some point we knew we were onto it; things were really going good and Bingo, one fine day, the guys are walking down the passage and there's a hole in the floor 20 metres in diameter. A great big borehole going down. We throw a rope in and 60 metres later—a 200 foot free fall—guess what? Another dive. There's no ledges, no nothing, no place to put your diving gear, so you have to put your tanks on at the top of this damn thing and repel 200 feet down and free fall into the water. That was Sump #7. Needless to say, the troops said, "This one's yours, Stone." We were there for three months and we pushed the logistics of open-circuit technology to the absolute max. There were some great stories on that trip.

a.c Is that when you started working on your closed circuit system?

S: Yeah. We got back from our trip and were scratching our heads, Noel Sloan, an M.D., John Zumrick, who was the Chief Medical Officer at the Navy Experimental Dive Unit and myself. Zumrick who was infinitely familiar with the Mark-15s and the Mark-16 which was still in development said, "What you need to do is start looking at closed circuit technology if you want to have any chance at all of finishing this project." That was it.

I spent all of 1984 doing research—that's my bag professionally. The next year I spent a great deal of time at the Navy Experimental Dive Unit in Panama City tearing apart the Mark-15. I just kept going through the beast and the manual until I knew it from rote. Once I had a handle on the system the next step was to modify it to get it to do what we wanted. The problem with military rebreathers is that they don't have sufficient redundancy. You cannot use them safely for cave diving unless you have a lot of peripheral bail out equipment.

I immediately had 36" drawings made up with our modifications and gave our big spiel to Biomarine. They said, "This is really interesting, let us think about this." Three weeks went by, four, five weeks. I finally called them up and they said, "Well, we think your idea's really interesting and we'd like to help you out, but the best way for you to do it is simply to buy a couple of rigs."

a.c: Back to the drawing board?

S: Our initial designs were essentially oddball spin-offs of the Mark 15-5. I had to spend the time to find out that it just wasn't going to work and realize I couldn't turn a pig's ear into a silk purse. My next steps were to start reading up on physiology and everything related to control systems which was new to me coming from structural dynamics. I also had to start picking up a lot on the mechanical design. It's really an interesting problem because of the trade-offs between buoyancy and size; anything large enough to do what we wanted closed circuit-wise had buoyancy problems, so you start adding lead and end up going full circle. Eventually you find yourself doing very serious optimized structural design to to minimize the volume and achieve the desired functionality because the volume controls the system's buoyancy.

Finally in the fall of 1986, I gave a talk on my ideas. Everybody sat there and listened politely to my structural notes and statistical probabilities, and they said, "This is very cute, Stone, but you're going to have to build it and prove it to us."

All told it took three years to actually "bend metal," as the aerospace people would say. The result was what I would call the Mark-1 and it was this 195 pound behemoth. I'll bet it was the first diving apparatus—life support system—that has ever been statistically designed to be fault tolerant from the ground up. That's what controlled the architecture. I wasn't too worried about compactness initially. Our approach was to get the functionality into the system and try it to see if it worked. Then we could start thinking about optimization. Long before that, we' had begun writing the microprocessor control program. By 1987 we had an operational system driven by four onboard processors. That was the unit we tested at Wakulla.

a.c: So Wakulla was really an offshoot of your work on Huautla and the rebreather.

S: Exactly. We needed a good clear water site that had variable depth to around 300 feet. The State of Florida had just acquired Wakullla Springs and it seemed like an ideal location. So I immediately called up Sheck and Paul DeLoach and said, "Hey, guys, I'm putting together a proposal to do scientific research on life support systems at the spring. Do you want to put a rider on to do some simple exploration?" And they said, "you bet." So they helped me write the exploration side. In fact, De Loche, Zumrick and Mary Ellen Eckoff had been the only three people ever to dive in that spring legally until then.

I submitted our proposal with the primary objective being our work on closed circuit systems. The second objective was to do a little exploration. The State got back to me and said "This proposal is extremely intriguing and we would like to follow up on this. However, we feel that your priorities are in error. We would like to see exploration be first." At which point I was going, *the sky has just opened up and rained bread. Those boys in Florida are going to have their day.* I called them up and said, "Guess what?" That was the fall of 1986. In December we got the go ahead on the project. We eventually got started the following October.

a.c: Didn't you get involved in the Andros Project with Rob Palmer and Stuart Clough about the same time?

S: The project was based on Pete Art's geological project out of the University of Bristol. The objective was to go down there and collect deep stalagmitic material which contained uranium records of the date at which the ocean level receded to that point (see "Blue Hole" by Rob Palmer pg.14). Palmer and I had done some trimix diving at Wooky Hole. Emboldened by our success, Palmer launched the International Blue Hole Project. I was the US coordinator.

Originally, we were going to bring the Mark.1 to Andros because we were expecting the site to hit 500 feet. However by springtime, I was heavy into Wakulla and the rig design was falling further and further behind. Palmer was insistent, "We've got to find a rebreather somewhere." It just so happened that Palmer caught a British PBS program called *Beyond Tomorrow* or something. Lo and behold, there was Stuart Clough on the telly with his Mark 15-5 making a chamber run at Fort Bovisand. It was the first time any of us had heard about his system (See the Clough interview: *"Closed Circuit Intervention"* pg. 31). He made the call.

a.c: That was your first closed circuit operation?

S: Right. We only had about 10 days of rebreather diving before the Carmellan crew had to bolt. There we were with a ton of heliox and open-circuit equipment so we had the chance to do some serious open circuit heliox dives. Our thinking at the time was "Why screw around with trimix? Let's be level-headed at depth and stay frosty. We had work to do. We limited ourselves to 40 minute screamer dives to 300 odd feet/92 meters; with the five hour decompression penalty you'd freeze your ass off in the 78 degree water in that amount of time. For the next month we dived, took data and collected stalagmites. We were on a roll. That was the set-up for Wakulla.

a.c: Wasn't that your tie in to Bill Hamilton as well?

S: That was the key connection. Hamilton had been working with Stuart Clough and showed up on Andros. As soon as we met we established this nuclear bond. I said, "Man, we've got a project going on this fall which you should be involved with." We ended up going down two parallel paths. I worked with Bill and the NEDU to generate tables based on Solomon's algorithms. Our goal was to cut down the decompression time by taking a radical approach on gas switches. So Bill came up with the now well-known idea that you go down

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How long (circle one): New, 1 2 3 4 years
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6. Total number of dives logged: ____,
Number of dives logged in the last year ____.
7. Have you been bent? ____ Y ____ N,
Number of times: ____
8. Your diving applications
(Indicate 1, 2 or 3 w/ 1=primary, 2 = secondary, 3 =occasionally)
____ Commercial; ___offshore ___onshore
____ Military
____ Law Enforcement
____ Search & Recovery
____ Scientific
____ Technical; ___ cave, ___ wreck, ___ reef
___ instruction, ___ photography, ____ film
____ Recreational
9. Diving industry member (check those that apply);
____ mfrg. ____ distribution ____retail
____ resort ____ instructor ____ divemaster
10. Total investment in diving equipment (US dollars = ∫1.5);
____ 0 - US$2499
____ $2500- $4999
____ $5000 - $7499
____ $7500 - $9999
____ $10,000- $12,499
____ $12,500- $14,999
____ $15,000- $19,999
____ $20,000- $24,999
____ $25,000- $34,999
____ $35,000- $49,999
____ Over $50,000
11. Technology utilization (1 = use regularly, 2 = use occasionally, 3= have dived, 4 = have not dived):
____ enriched air nitrox
____ oxygen decompression
____ trimix/heliox
____ special tables
____ desktop decompression s/w
____ full face mask/helmet
____ dry suit
____ hot water suit
____ diver propulsion vehicle
____ surface supplied system
____ semi or closed circuit rebreather
____ diving bell
____ one atmosphere diving system

12. How would you rate your interest in semi and fully closed circuit equipment?
(Indicate 1 = high, 5 = none): ____
____ Presently own
____ Don't own, ____ Plan to own.

13. What would be the primary benefits of C2 in your application (Mark all those that apply on a scale of 1 to 3, 1= most important, 3= least important):
____ Extended gas supply
____ Optimal decompression
____ Optimal mix
____ Lower operating cost
____ Less bulk
____ Silence (no bubbles)

13. Maximum required depth range; ____ feet / metres.
Maximum required dive duration: ____ hours.

14. What is the maximum price (per system) that would make a semi/closed circuit equipment feasible for your application(s) (US dollars = ∫1.5):
____ $1500-$2499
____ $2500- $4999
____ $5000- $7499
____ $7500- $9999
____ $10,000 - $12,499
____ $12,500-$14,999
____ $15,000- $19,999
____ $20,000-$24,999
____ $over $25,000

15. Would you consider purchasing one or more of the following:
Fully closed rebreather ____ Y ____ N ____ Maybe
Semi-closed rebreather ____ Y ____ N ____ Maybe
Oxygen rebreather ____ Y ____ N ____ Maybe
Priority (check one);
____ Fully closed, ____ semi-closed, ____oxygen

With regard to Semi and fully Closed Circuit equipment:

16. How important is system redundancy to your diving application? : ____
(On a scale of 1 to 5, 1= essential, 5= not important)
Minimum number of minutes required for bailout time ("time to safety")?: _____ minutes

17. How important is having an onboard dive computer that monitors gas and decompression? : ____.
(On a scale of 1 to 5, 1= essential, 5= not important)

18. How important is being able to integrate a full face mask/ helmet? (On a scale of 1 to 5, 1= essential, 5= not important): ____.

19. What is the maximum system weight that is acceptable (In pounds):
____ under 20 lbs.
____ 20-40 lbs
____ 41- 59 lbs
____ 60-79 lbs
____ 80- 99 lbs
____ over 100 lbs.

20. Would you like more information on semi and closed circuit equipment?
____ Y ____ N

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on heliox and then come back on various nitrox mixtures, including air in the habitat, and then O_2.

a.c: History in the making. Wakulla obviously came off well and you spent 24 hours underwater on the Mark-1. What was your next hurdle?

S: After Wakulla, the prime motivation was to redesign the Mark-1. Although it was ungainly in weight, it had outrageous range. Our next challenge was to get the Mark-2 down to 130 pounds. We did that. Then we began tackling all the little operational problems. We did a good bit of diving on the systems in the fall of 1989 and then it kind of languished. That was the point we brought in Richard Nordstrom as CEO for Cis-Lunar, pulled in a couple more engineers, and things took off. It's been refinement after refinement ever since.

a.c: Has it just been a matter of resources? If you had a couple of million in the bank could you have done it a lot quicker?

S: Even if we'd had the money... it's been an extremely painful process. We've got probably 25,000 man hours if not more into the design of this rig. We're now up to the Mark-4, which we were diving this spring, but the changes that went on between the Mark-2 and the Mark-3 were immense. Architecture, reliability, functionality—we really started to learn what the hell we were doing with the Mark-3. The jump between the Mark-2 and the Mark-3 was as great as the difference between the Mark-1 and nothing—a huge difference in terms of operational capability. We took the Mark-3 down to Jacksonville in the spring of 1992 and spent six weeks putting it through its paces. Everybody came back with a ten page list of "fix this and then we'll have a great system." We spent the next ten months doing just that. Sixteen thousand lines of code later we had the Mark-4. It's gotten to the stage now when I'm diving, that I'm not even thinking about how many solder joints are in the computer system.

a.c: How does the Mark-4 differ from other rebreathers on the market? What makes it unique?

S: The main effort was put into the work of breathing. That's the most critical aspect. Forget about controlling gas mixtures and things like that for a moment. The critical question is can you breathe on it underwater? A poorly designed rebreather will breathe like a dog and require tremendous amounts of work to inhale or exhale. It all depends on the counterlung or breathing bag. The position and geometry of that bag are the difference between night and day, between a Chevy and a Cadillac, actually a Chevy and a Ferrari would be a better comparison.

a.c: Most of the systems on the market seem pretty much the same with regard to breathing bag design.

S: That's right. For example a pure oxygen rebreather has a dense bag that sticks out on the front of your chest and tends to have very high positive inhalation pressure. It feels like it wants to blow the frigging regulator out of your mouth. The other side of that coin, is the Mark-15/16 type system that has the bag on your back It's the exact opposite; you have to work to draw the gas into your lungs. From a physiological perspective that's much worse than the situation imposed by say the front mounted LAR-V which is used by USN combat swimmers. Your lungs prefer to be loaded inhalation-wise as opposed to exhalation. The way you can tell that is to blow up a balloon. It's easy, right? Your lungs really don't complain too much. Now try taking a plate and sucking the plate so you can hold it by maintaining the vacuum. Your lungs are screaming. Lungs abhor a vacuum. That's effectively what you have to do to pull the gas out of a Mark-16. Every time you breathe you're doing that Delta H transfer of mass into your lungs. What's more is that this work load can be modeled as a sinusoidal curve. I'm giving you Rebreather Design 101; I'm not going to get too much in depth here. Suffice it to say that you can create a computer design program to investigate all the possible shapes of the curve to meet the needs of the human body and get it within a very, very tight tolerance of the desirable threshold pressures. That's what I did in 1988 to come up with an optimized shape for the counter-lung. That was the basis for our patent. We utilize a split counterlung that fits over each lung and shoulder. It's fundamentally different than other designs.

a.c: Next generation.

S: We also have spent a lot of time looking into things like manual control systems. If you need to get at your gas controls on any of the existing military units you have to reach way back and find the buttons. That's the situation that we had at Andros, the manual controls were a dog. So we came up with this idea of completely re-routing all the control systems into something that can be easily grabbed by one hand. We tested that idea with the Mark-1 and it looked like the space console for...

a.c: I remember the pictures.

S: Eventually we condensed that down to compact size and mounted it on the front of the rig, so that the operator has complete control for directing oxygen flow, directing gas flow, shutting off various systems in case of a problem. This was all mission-driven by cave diving.

In fact the whole system was designed to be fully redundant in the closed-circuit mode and fully field configurable. It's modular. The diver can say "I understand how this module works; I'm going to re-pipe this, I'll put this over here, I'll reorient over here, I'll put these bottles over here. Now I've got redundant gas supply." We've built one to two kilometer range systems, highly efficient in closed circuit mode with a pretty slim likelihood of anything going wrong. If it does you can go on open circuit bailout. With a single configured unit we don't go any further than our bailout can cover. Or you can configure a fully redundant explorer mode with completely dual systems for long distance runs.

a.c: You're saying you can actually re-configure the rig based on the application you're diving?

S: On-site.

a.c: Wow.

S: And if you find that you're getting beyond that range, you come over, strap another module to the backpack, redo the connecting pneumatics—it's fairly straight forward because it's all flexible. And Bingo, you're off and running.

a.c: I understand the mouthpiece that you've developed is pretty trick.

S: We spent a lot of time designing the mouthpiece and have several patents on it. You can throw a switch and you're in open-circuit mode. For example if you had a catastrophic failure and needed to switch systems in a double-rig, you would simply throw this thing into open-circuit, blow the gas out, take a breath for the transfer, grab the second hose which is idling in open circuit mode, and blow into that. If you need another breath you've got a breath and when everything is copacetic, you switch back and you're on system #2. You simply acknowledge to the computer that you're active on the new system, it carries your decompression and away you go. Once you've gotten into the habit, you realize how easy it is. The time pressure goes away. If shit hits the fan, you've got another eight hours—eight hours!

a.c: What's it like doing your own test diving?

S: A classic story. We get to *Cueva Infierno*, which literally means "cave from hell" in Spanish and we're down there in this very spooky place—a 20 meter diameter dark brown tunnel leading down into this underwater pool.

To make a long story short here, each diver was putting their system together and methodically going over everything. Double-checking it. Triple-checking it. Finally they're ready to go and Noel Sloan leans over to Lee Porter and says, "Scoop bootie brother," which in caving slang is a slang means, "Go discover a virgin tunnel." And Porter who was looking at his LED says, "I'm going to be taking this slow," which in essence meant, *"This is still an experimental piece of apparatus and it's on my butt, and I'm in some godforsaken remote tunnel at 3600 feet elevation and there's no chamber and it's going to take a week to get me to a chamber if I needed one and I'm going to take this slow."* Of course they took it real slow and had a nice dive but the point was that it was for real. We knew what the difference between reality and simulation meant right there. Everybody had a chance to experience it. Boy it was sobering.

a.c: Reality!

S: The main mission driving all of this is that it's got to be super reliable to be able to be used for cave diving. So if anything goes wrong at any point, it's no sweat. It's like "So what; we've got another eight hours." That's the thing that kills cave-divers. If you look at the records over the last ten years there's probably 50 or 60 people who have died—it's largely been due to panic. Or a situation where the diver gets himself into a corner where time becomes the critical element.

The classic example where a man had all the right stuff and didn't survive was Parker Turner. There was a guy who runs cool as a block of ice, and nobody else to my knowledge besides his partner could have done what they did (see *"The Accident Report From Indian Springs"* by Bill Gavin, Technical Diver 3.2, 92OCT). They were trapped in the cave for an hour and a half at 140 feet/43 metres with limited resources, trying, trying, trying to get themselves out.

a.c: The fact that Gavin got out was a testimony.

S: They remained cool to the end. It was not in their minds to panic. That was proven clearly. But if they had a system that was not as sensitive to range the way open-circuit equipment is at depth... The point is that when you go to closed circuit, all that goes away.

a.c: It's going to change the whole mind-set of diving.

S: We've spent the last four years honing the mechanisms such that the likelihood of failure is extremely small, even if you're a real jerk. The system can tolerate flooding. No one else's can to my knowledge. For example, when we were out on Andros in '87, it was understood that if your mouthpiece came out and you put it back in and heard gurgling, that was it. You had to go for your bailout and get the hell out. That was the bottom line. We can recover from a full flood on this thing.

a.c: You can recover from a flooded canister as well?

S: Yes. It's part of our patent. Hang around tomorrow and I'll give you a demo. As I said, we've tried to build these systems so that you can abuse them and then still have them work. We saw lots of abuse this past spring. We logged 166 missions on the rigs, almost 300 hours of underwater time at depths down to 80 meters.

You have to understand, these guys don't view this thing as some holy piece of equipment but rather as utilitarian chunk of hardware. That was the big change that took place this spring. That's why I say this was the threshold year. The bottom line is that the system has the redundancy that we felt was needed. It's gonna be our asses with a backpack on them.

a.c: While we're on the subject of safety let me change topics a bit. How high do you run your PO$_2$s during operations?

S: We typically use a 1.0 set point. We've had a lot of philosophical discussions about it. Carmellan has played around with 1.3 and 1.4. I might also add they've been known to have problems. One of them had an O$_2$ hit a couple of years ago due to a solenoid that failed in open position and dumped a lot of oxygen into the system. The fact they had been running at 1.4 for awhile most likely contributed.

a.c: Spiked their O$_2$?

S: The problem is that your body gets loaded and when you push it up you're much more sensitive to a spike than you would be if you had been running at 1.0.

a.c: Richard Vann at Duke University told me that (see *"Oxygen Tolerance Management,"* by R. Vann, pg. 54). He's had a lot of direct experience with oxygen rebreathers. Apparently military divers have had problems with spikes—sudden depth changes. Apparently the enzymes that protect the body from high PO$_2$s get used up and then the spike hammers you. At tek last year he gave a talk and people asked him how high he recommended running working PO$_2$s. His recommendation was "1.2," which nobody wanted to hear.

S: It's interesting the Navy is backing down to a PO2 of 1.3 and you're saying Vann wants 1. 2. We're already at 1.0. I guess we're leading the pack.

a.c: I've heard a lot of people say that your system is just too big.

S: We could make the system a lot smaller if it was purely a sport unit. We've had to leave space to allow the divers to configure into an explorer model. We've also oriented the stack (i.e. canister—see tek.TERMS pg. 68) horizontally to reduce the vertical height of the unit. That's one of the reasons it looks so different. Once we get away from the cave-diving/ mission-driven scenario model, we're probably going to be able to reduce the size by 30% and cut the weight by a factor of two. Yeah, everybody's always on me, "It's too heavy stone; get light." We'll get there.

a.c: How about training? How long will it take for someone to train to use the Mark-4?

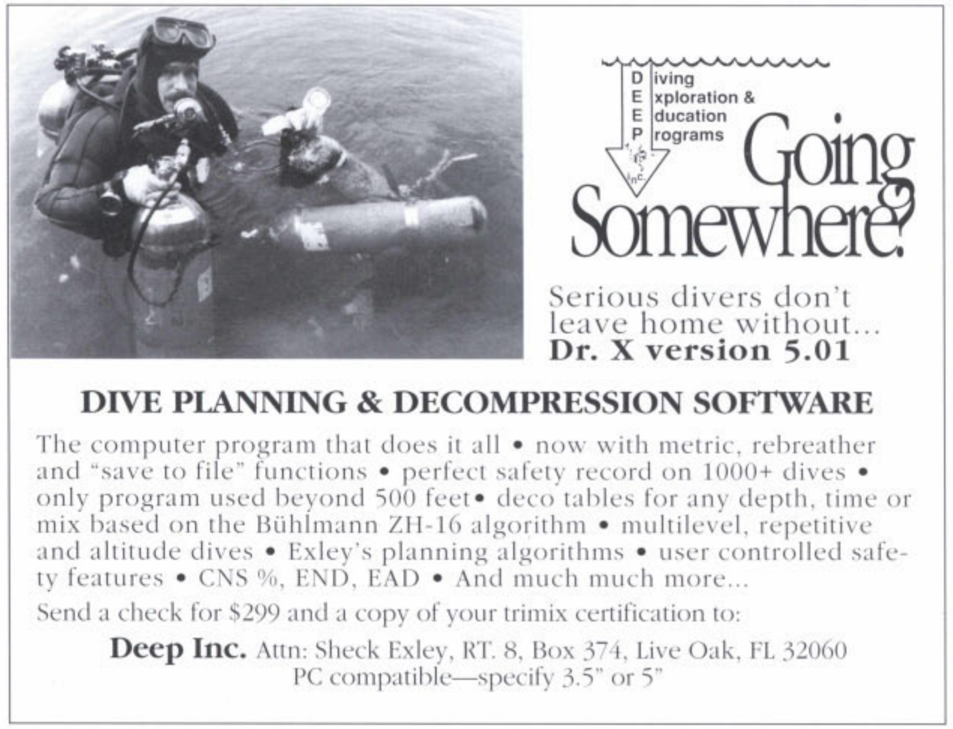
S: If you're an advanced diver I could get you off and running in about 10 hours. With the double rig it takes more like 20-25 before you feel real comfortable with it.

a.c: How much of that is emergency procedures, knowing what to do when something goes wrong?

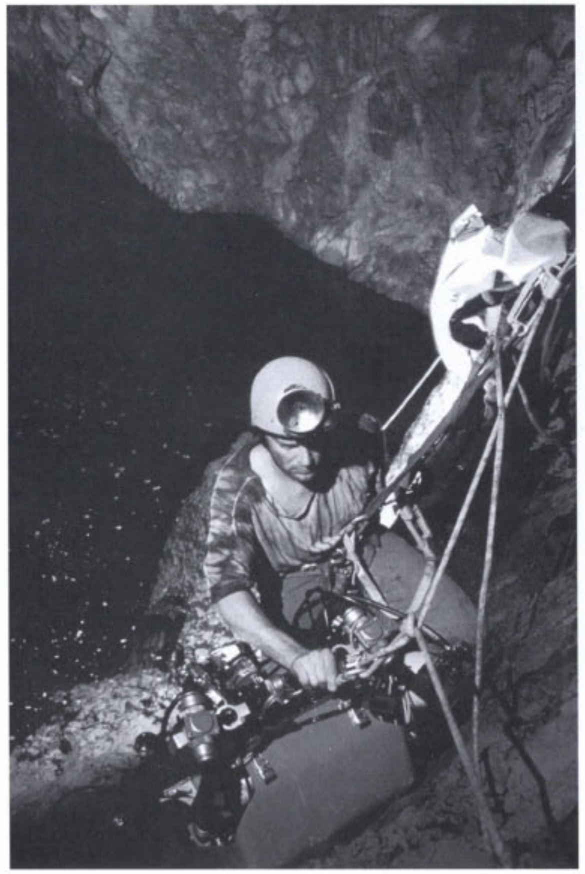
S: Almost all of it. Its like telling someone they can be a co-pilot and you get up in the air and say, "OK, you fly." And the guy says this is pretty cool I'm flying. But is he landing? Is he taking off? What does he do if you tell him to vector north because they've got inbound traffic? Things like that. It's gotten to be taken in steps.

a.c: We've been talking about a lot of capability that will be available to support diving operations in the future. What will technical divers be doing 15 years from now in diving?

S: People will always be bold. Exley is about to do a 300 meter. There's a man who's got a focused mission. He simply uses technology that he's comfortable with until it can't go any further and he's bound and determined to crack 300 meters. I hope he



does it. He'll be the first human to do a surface-to-surface 300 meter dive. I wish he was using a rebreather; it would eliminate a lot of the reliability factor. That's what happened to Hasenmayer. He was rehearsing for a 300 meter dive in a Swiss lake. He had a regulator malfunction and had to omit decompression on several stops. As a result he ended up getting a helium hit and was paralyzed. Sheck is a dear friend and we go back a long way. If anybody can do it, he can. The guy has got such control, in fact many people believe that he's not human. Eventually I'm going to talk him into rebreathers because it's really the way to go for the stuff like that.



Where will the real cutting edge be in 15 or 20 years? I think we'll be doing thousand to 1,500 foot dives (300-460 meters) off a wall on hydreliox. We've learned enough tricks with what we've done with the Mark-4 to easily build a hydreliox machine on your back and make it work. You'll go out there and blow your stacks and skydive down to 1500 feet off the wall, re-blow, bounce back up and probably get yourself a five to seven hour dive if you do it properly.

Of course rebreathers aren't going to get us over the decompression hurdle. Unless we come up with something new, we still have that barrier to deal with. That forces you to go to unusual regimes if you're going to do something unique like applying commercial methods. We've already had discussions of putting a habitat at 250 feet (77 meters) inside the main tunnel at Wakulla and using that as a transfer station to bring the guys out. They'll go down, do their mission, come back to the habitat which will have it's own environmental control system. I can do that right now with the control system on the Mark-4. I can drive the habitat to maintain that depth.

a.c: So you'd put them in saturation.

S: They'd come back, lock-in to a transfer capsule and be hauled up to the surface under pressure. You'd have to have either a crane or a gantry or some simple system that would allow you to pick it up and lock it into a chamber. They get a night's sleep, eat, and then next day you'd transfer them back down all recharged and ready to rock-and-roll.

a.c: It's done everyday in the North Sea. It's just at a different level. It's going to be an exciting future.

So what do you want to be when you grow up: an explorer or the head of a rebreather company?

S: It all started for me with Huautla but I guess the big change took place in 1990 when we hired a CEO to make Cis-Lunar a business. I am merely an engineer now. I really don't have anything to do with the daily operation of the company. That's the CEO's job. I have a lot of input into how things might work, but there's eight other engineers who are driving this project now. It's taken off; it's on its own.

a.c: Are you're still working your regular, ah um, your irregular job at the US Geological Survey?

S: About 40-50 hours a week there and about 50 hours here.

a.c: At some point you'll just cut it off and...

S: And be working a hundred hours a week...

a.c: Doing what you love.

S: We were here two weekends ago with the entire engineering team and that's a pretty righteous group. The topic of discussion was the Mark-5; it's going to be out there. Everything that we've learned is now going to be put into this device, fully-targeted for production. It'll be quite different from the system we're using for cave-diving. I could work on that 7 days a week.

If you don't have a mission, you don't tend to want to invent new technology. My role in this whole thing is being out there on the edge with the equipment, then coming back with the ideas and saying, "If we can do this, we can do this!" Eventually we're going to transfer this technology into low-pressure spacesuit designs and start looking at getting private operations in orbit.

a.c: I've heard that you wanted to go into space.

S: A couple of years ago when we were really embroiled in this, trying to get Huautla done, I was feeling that I was just going to retire from all this crap. I couldn't even think about how I was going to get from point A to point B. It was about that time I was wandering around NASA, seeing what was going on, and I realized that what I really want to do is to get a long duration group into orbit and then try to get back to earth. Unfortunately I get myself in trouble every time I talk about that. What an arrogant son-of-a-bitch, thinks he can put his own space program together. I just stopped talking about it.

a.c: Do you foresee having a commercial space industry?

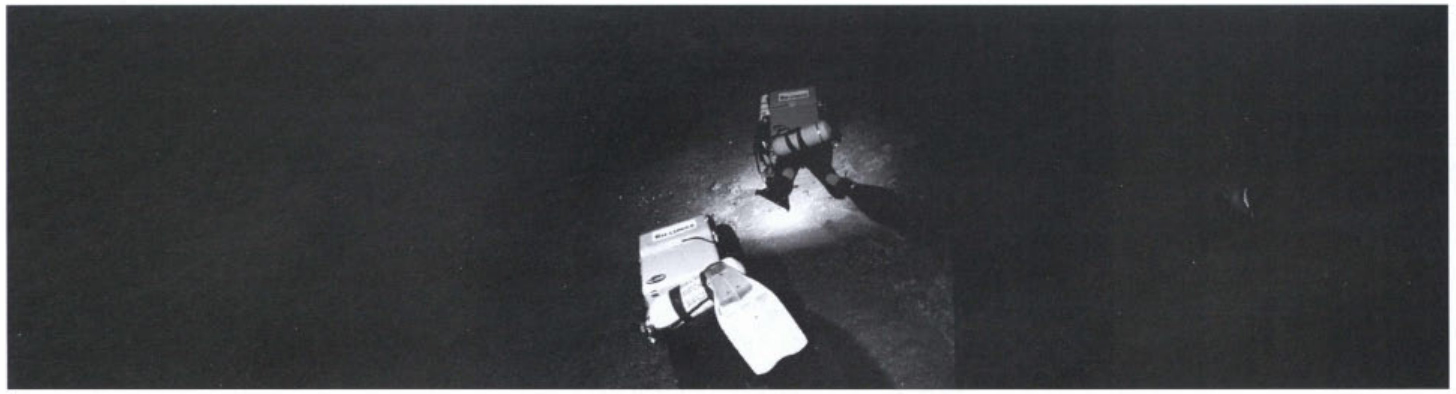
S: The fact of the matter is that it's being pushed in that direction by our generous Congress who is on the verge of voting the space station out of NASA's budget as well. That's probably good because they can't spend that money well enough to get the rest of us up into orbit. They have just enough money to put a few lucky astronauts up there, a week up in orbit and then they come down. How does that benefit the rest of the populace? It's time for us grunts to take over the reins and figure out a way to get up there economically.

a.c: The final frontier.

S: We're going to end up taking all the technology that we've developed and build suits that are basically no more than workman's overalls. They're going to cost about a hundredth of what is presently being paid for a one-of-a-kind aerospace product. Down the line we'll move into spacecraft life support systems. That's the way to go and I think we're going to find partners all along the way to participate, just like we're doing now.

a.c: Where do you go from here?

S: It's now at the stage where the unlimited possibilities are starting to unfold. It's just starting to get fun! I have climbed little steps, and all of a sudden I've gotten over the rise and I can see where the next steps are. The next couple of years are going to be real interesting.



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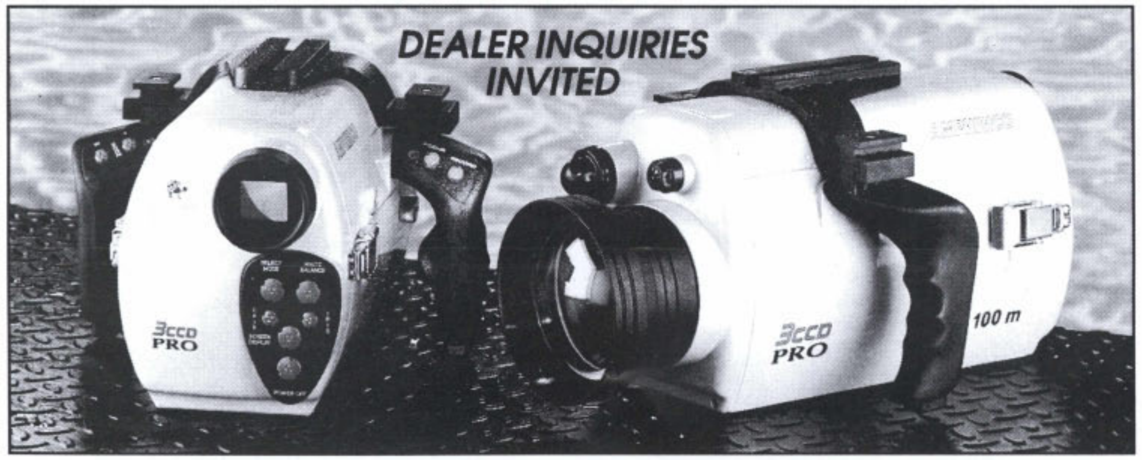


Combat Swimmer

On March 10, 1944, Royal Navy Lieutenant James Kull took a deep breath of the warm night air, exhaled, and slipped quietly beneath the surface of the Johore Strait in Singapore Harbor. His next inhalation was composed of pure oxygen, tainted only slightly by the rubber hoses and canvas breathing bags of the closed-circuit rebreather he wore. In the silence and darkness of underwater Kull began swimming steadily and watching the luminous faces of his compass and depth gauge. Straight ahead, 2000 yards away, the Japanese heavy cruiser Amagasaki lay at anchor

For the hundredth time, Kull mentally went over the procedure of attaching his high explosive limpet mines to the hull. He again imagined the sequence of steps, until the sensation of increasing ear pressure brought him abruptly back to reality. He glanced at his depth gauge. It read 19 meters. A flash of fear shot through him as he remembered the warning not to swim below 15 metres with the new equipment. He sucked in a deep breath of oxygen and kicked hard to rise. Kull knew that some of the divers who had exceeded the 15 meter mark during training had suffered underwater convulsions and blacked out, but no one seemed to know exactly why this occurred. Nor did anyone understand why only a few of the divers had sustained the mysterious attacks.

As he approached the safety of the 15 meter level, his breathing slowed to normal. He continued on his determined, silent run toward the ship.

Kull's mission was successful. Two hours later the giant Amagasaki erupted in a pillar of fire and sank to the 20 meter harbor bottom, its back broken by the combined explosions of three limpets—but Kull never saw the results of his effort. At the moment of explosion he lay motionless under the doomed ship, a victim of the dreaded oxygen convulsion that had struck without warning as he worked frantically to attach the last mine.

The devices worn by the British frogmen in the Pacific during World War II were closed-circuit pure-oxygen rebreathers. In spite of the known hazards of oxygen poisoning, these closed-circuit diving units were used because no exhaust bubbles escaped to betray the underwater swimmer. Divers and military authorities learned, in time, to respect the strict depth limitations of oxygen rebreathers and today the units are considered safe for long periods of time only when used in water shallower than 25 feet/8 meters.—Larry Cushman 1969

A special thanks to *Skin Diver Magazine* for allowing us to print this excerpt from:
Cushman L, 1969JUN, Cryogenic rebreather, Skin Diver Magazine, p. 29-31, 85-87.

OXYGEN EXPOSURE MANAGEMENT

by Richard D. Vann

Knowledge of central nervous system (CNS) oxygen toxicity is unnecessary in order to breathe oxygen underwater safely at a partial pressure of one bar or less. Considerably more knowledge is needed at higher partial pressures or when the oxygen pressure changes with time. The real questions are; how much oxygen can be used safely given our current knowledge, and how can oxygen be used more effectively without sacrificing safety?

The Biochemistry of Oxygen Toxicity

Oxygen metabolism is the primary energy source in higher life forms. Because heat energy produced by oxygen reactions such as fire would damage tissue, metabolic pathways have evolved that safely capture small packets of reusable chemical energy. This energy is stored in molecules called adenosine triphosphate (ATP).

Figure F1 illustrates some features of ATP production during the breakdown of sugar at normal oxygen partial pressures. The biochemical processes known as glycolysis use no oxygen and produce relatively little ATP. The major product of glycolysis, pyruvic acid, enters the Krebs cycle which releases carbon dioxide and supplies electrons needed to form ATP. Most ATP is produced in a series of electron transport reactions called the respiratory chain.

Oxygen usually does not enter the respiratory chain until the very end where it reacts with hydrogen to form water. Should oxygen enter the respiratory chain prematurely, molecules like the superoxide anion (O_2^-) and hydrogen peroxide (H_2O_2) can form. These reactive species of oxygen are potentially toxic but are deactivated by protective enzymes such as superoxide dismutase and catalase.

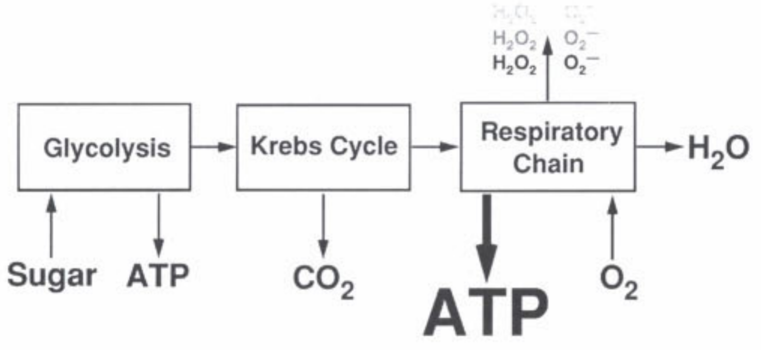
When the oxygen partial pressure is raised Figure F2, the production of reactive oxygen species increases and may overwhelm the protective mechanisms. This can initiate biochemical and physiological changes that interfere with normal function and cause signs and symptoms we know as oxygen toxicity.

Signs and symptoms of convulsions are the most spectacular and objective signs and symptoms of CNS oxygen toxicity, but there is no evidence they lead to permanent damage if the oxygen exposure is discontinued promptly. This assumes, of course, that drowning or physical injury are avoided. Experimental oxygen exposures are often terminated by less specific symptoms including abnormal breathing, nausea, twitching, dizziness, uncoordination, and visual or auditory disturbances. These symptoms do not necessarily precede convulsions. Factors which elevate cerebral blood flow, thereby augmenting oxygen delivery to the brain, appear to increase susceptibility to oxygen toxicity. These factors include immersion, exercise, and carbon dioxide. Carbon dioxide may be present in the inspired gas or may be retained due to inadequate ventilation. Inadequate ventilation can be caused by high gas density, external breathing resistance, or poor ventilatory response to carbon dioxide by "CO_2 retainers."

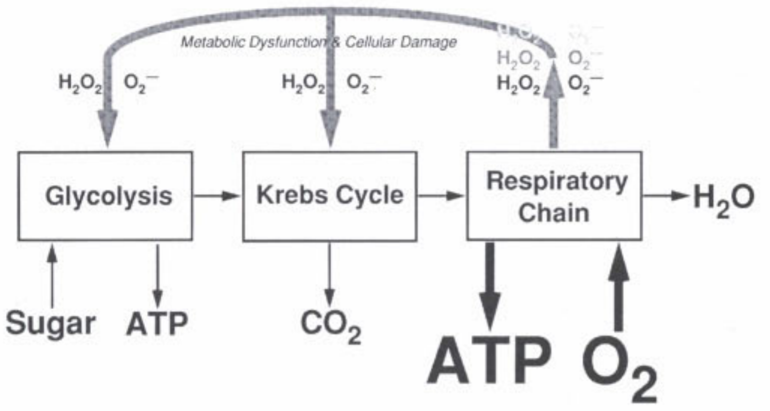
Oxygen Exposure Limits

Oxygen exposure limits like those of Figure F3, were established to decrease the risk of convulsions for divers breathing pure oxygen or oxygen in mixed gas. Figure F3 shows three sets of pure oxygen limits and two sets of mixed gas limits. The U.S. Navy limits from the 1973 Diving Manual (USN 1973) were published in the 1979 NOAA Diving Manual (NOAA 1979). The Navy has since modified its pure oxygen limits while NOAA has modified both the pure oxygen and mixed gas limits for its 1991 Diving Manual (NOAA 1991). Compared with the 1973 Navy/1979 NOAA limits for pure oxygen, F3 shows that the 1986 Navy limits are less conservative while the 1991 NOAA limits are more conservative. For mixed gas, the 1991 NOAA limits are less conservative than the 1973 Navy/1979 NOAA limits.

The changes to the exposure limits of F3 reflect uncertainty concerning which limits are best and suggest an examination of the type of data upon which oxygen limits are based. These data are shown in Figure F4 and represent most of the CNS toxicity episodes that have occurred in U.S. experiments during wet, working dives at a single depth for pure oxygen or for oxygen in mixed gas. The squares represent convulsions, and the triangles represent symptoms.



F1 The production of ATP during the breakdown of sugar at normal (normoxic) oxygen partial pressures.

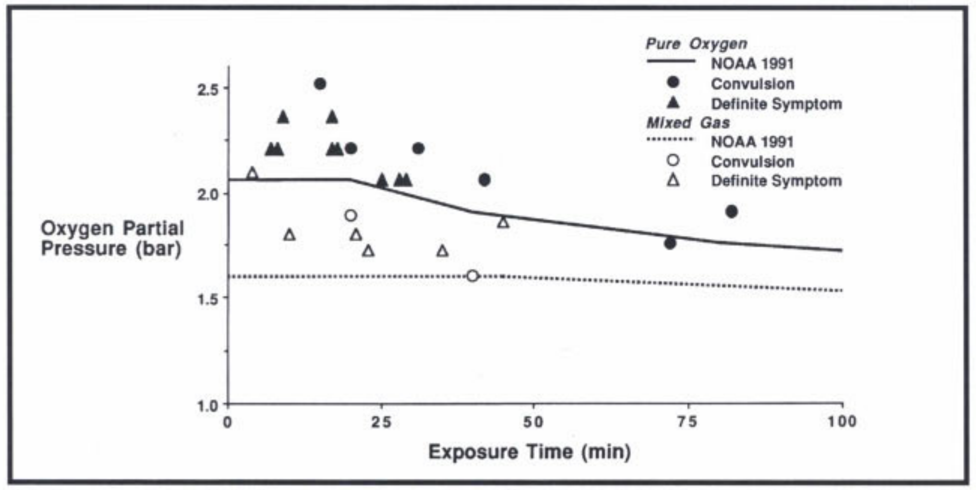


F2 The production of ATP and reactive oxygen species during the breakdown of sugar at elevated (hyperoxic) oxygen partial pressures.

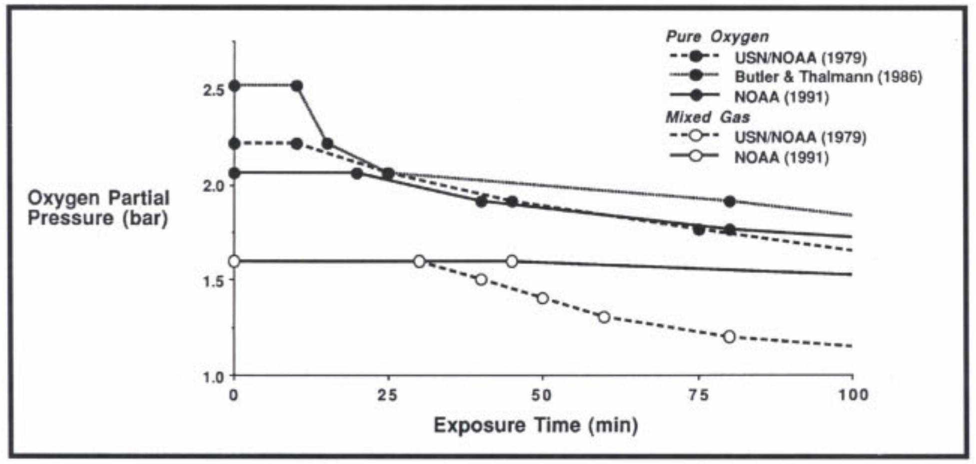
The 1991 NOAA limits are shown for comparison. While the discussion below is confined to U.S. data, Donald (1992) has recently published a large body of British data which will be very important.

The mixed gas incidents occurred at lower oxygen partial pressures than the pure oxygen incidents. Lanphier, who conducted oxygen research for the Navy in the 1950's, postulated that high breathing resistance during deeper mixed gas dives caused carbon dioxide retention which potentiated oxygen toxicity by increasing cerebral blood flow. This led him to propose more restrictive limits for mixed gas than for pure oxygen. In subsequent studies, the lowest partial pressure and shortest exposure time at which a mixed gas convulsion occurred was 1.6 bar for 40 min. The corresponding exposure for pure oxygen was 1.76 bar for 72 min.

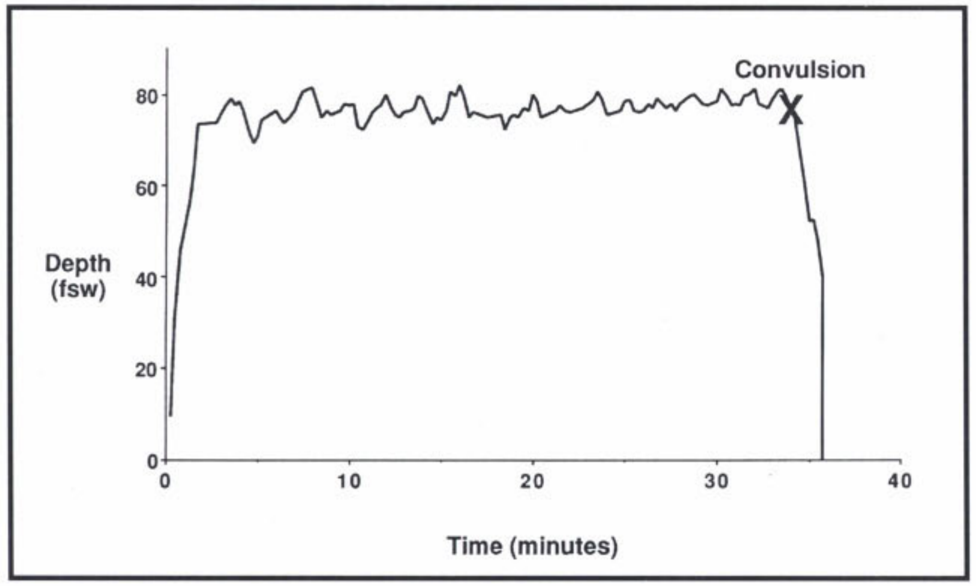
The mixed-gas convulsion



F3 Oxygen exposure limits for pure oxygen and for oxygen in mixed gas as published by NOAA and the U.S. Navy. The 1973 U.S. Navy limits (USN 1973) were adopted for the 1979 NOAA Diving Manual (NOAA 1979). These are indicated as USN/NOAA 1979. The Navy revised its pure oxygen limits in 1986 (Butler and Thalmann 1986). NOAA revised its pure oxygen and mixed gas limits in 1991 (NOAA 1991). Exposure times and pressures are connected by line segments to facilitate comparisons.



F4 CNS oxygen toxicity data (convulsions and symptoms) from U.S. experiments with wet, working divers exposed to constant oxygen partial pressures (Lanphier and Dwyer 1954; Lanphier 1955; Piantadosi et al. 1979; Vann 1982; Schwartz 1984; Butler and Thalmann 1984, 1986; Butler 1986; Lanphier 1992). The 1991 NOAA exposure limits for pure oxygen and mixed gas are shown for comparison (NOAA 1991).



F5 The depth-time profile recorded by a dive computer for an exposure on 32.8% nitrox at a nominal depth of 80 fsw and oxygen partial pressure of 1.26 bar. The dive was terminated at 34 min by a convulsion. After rescue, the diver was found to have an unreported history of convulsions and to be on anti-convulsant medication.

occurred after 40 min at 100 fsw during a wet, working nitrox chamber dive with a 1.6 bar oxygen set-point in a rebreather. Heavy exercise and high breathing resistance appeared to be contributing factors. Upon decreasing the breathing resistance and reducing the oxygen pressure to 1.4 bar, 110 dives were conducted with no further oxygen incidents during 60 min exposures at 100 and 150 fsw with both nitrox and heliox.

Is an oxygen partial pressure of 1.4 bar sufficiently conservative given the potential for depth control error, the unpredictability of carbon dioxide retention, and the minimal mixed-gas exposure data? The Navy is leaning towards a set-point of 1.2-1.3 bar for rebreathers where the oxygen partial pressure fluctuates during control around a pre-determined set-point.

The data shown in F4 suggest a need for separate mixed gas and pure oxygen limits but are insufficient to conclusively prove this need. As a convulsion underwater is potentially fatal, however, a cautious diver might wish to use separate oxygen and mixed gas limits until further data firmly establish they are unnecessary.

Open-Water Experience

What can we learn about oxygen toxicity from open-water diving with mixed gas and pure oxygen? The incidents described below took place within the past year.

A mixed gas fatality occurred in a southeastern U.S. cave where two divers breathed air for 15 min and EAN 40 (40% O_2, balance N_2) for 45 min at depths of 80-105 fsw. The oxygen partial pressure was mostly 1.4 bar but occasionally reached 1.5-1.7 bar. After 45 min of hard swimming on enriched air nitrox, one diver convulsed and lost his regulator. His buddy could not reinsert the regulator, and the diver drowned after a failed attempt to swim him out of the cave. The oxygen exposure was, for the most part, less than the 1991 NOAA limit of 1.6 bar for mixed gas diving.

Another enriched air diver who drowned after an apparent convulsion had told friends that the NOAA limits did not apply to him. His oxygen partial pressure was estimated at 1.7-2.0 bar for a bottom time of 45-50 min.

An incident involving pure oxygen occurred in a southeastern U.S. lake. After an 8 min exposure at 300 fsw on a trimix 14/33 (14% O2, 33% He, and 53% N2) a diver decompressed on EAN 32 to 20 fsw where he switched to pure oxygen. Prior to breathing oxygen at 20 fsw (1.6 bar PO2), his PO2 was 1.4 bar except for 7 min at 1.5-1.7 bar. After 20 min on oxygen, he unclipped from his decompression line to visit a nearby diver but drifted down to 35 fsw (2.05 bar PO2) and dozed off. (An Emergency Medical Technician, he had slept only 2 hrs the previous night.) He was awakened by abnormal breathing and the onset of convulsions but inflated his buoyancy compensator before losing consciousness. He recovered from near drowning after rescue on the surface.

It is commonly assumed that convulsions do not occur at oxygen pressures of less than about 1.6 bar, but this assumption depends on a normal seizure threshold. Figure F5 shows the depth-time profile of an 80 fsw dive that terminated with a convulsion at 34 min. The diver breathed EAN 33 with an oxygen partial pressure of 1.26 bar. After rescue, he was found to have an unreported history of convulsions and to be on anti-convulsant medication. While such a situation is rare, it emphasizes the uncertainty of our knowledge, the need to expect emergencies such as oxygen convulsions or decompression illness, and the necessity for emergency management plans.

Statistical Modeling

Do these open-water incidents over emphasize rare events? What is the risk of a rare event? We can estimate this risk by statistical modeling of oxygen exposure data.

Suppose the risk of oxygen toxicity increased with the concentration of the reactive oxygen species produced during hyperoxic metabolism (F2) and represented below by "X". Suppose also that the rate of change of the local concentration of X were equal to its production minus its removal. If X were produced in proportion to the local oxygen tension (c •PO2) and removed at a fixed rate (k), its rate of change would be

$$dX/dt = c \bullet PO2 - k$$

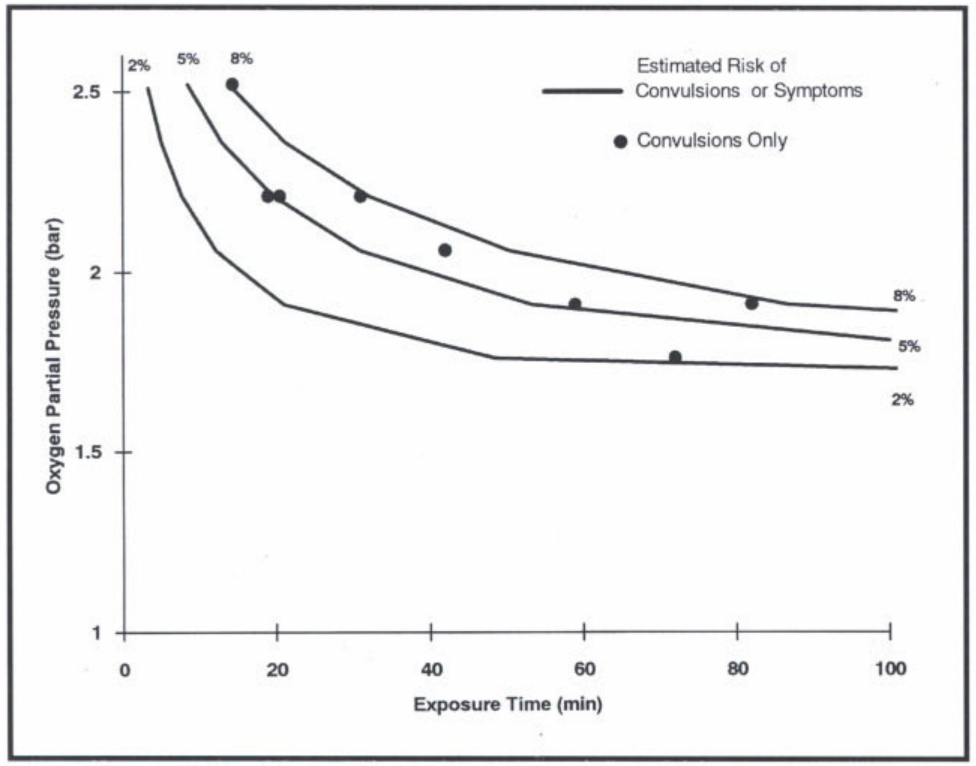
where c and k are constants. When integrated, this first order differential equation gives

$$(1) \quad X = (c \bullet PO2 - k) \bullet t$$

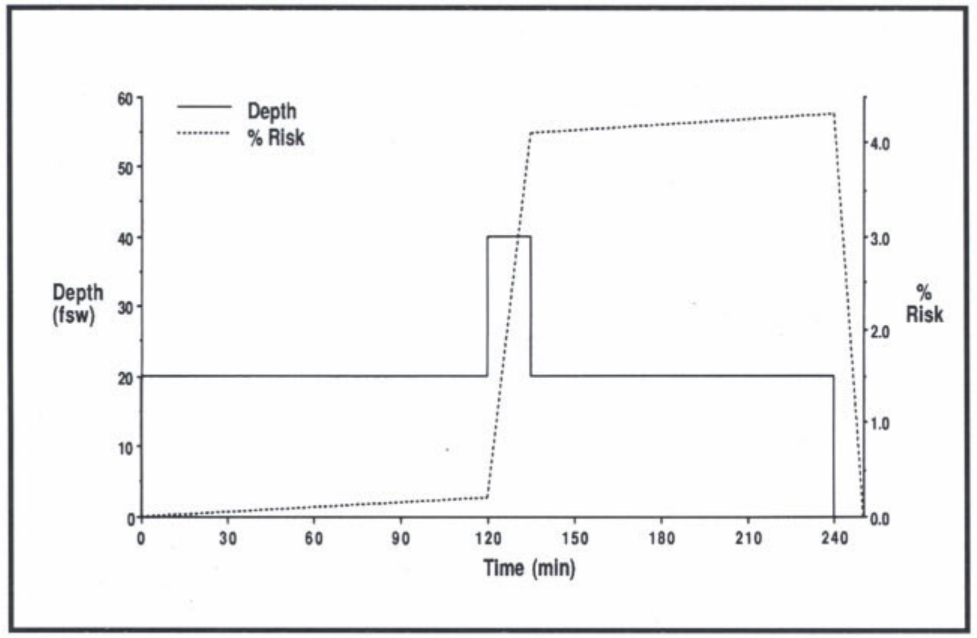
The risk of toxicity is specified by a separate function of X.

Equation 1 defines a family of rectangular hyperbolas proposed empirically for the pressure-time relationship of pulmonary and CNS oxygen toxicity. Statistical modeling derives this relationship theoretically and finds the constants c and k directly from experimental data. This allows the risk of toxicity to be estimated for any oxygen exposure.

Figure F6 shows three rectangular hyperbolas for 2%, 5%, and 8% risks of either symptoms or convulsions. These were estimated from data on 773 pure oxygen exposures. The convulsions, represented by black dots in Figure F6, occurred at estimated risks of 2-8%. In a context of risk, an oxygen exposure limit is the depth and time at the level of risk which is judged to be acceptable. In F6, for example, the limit for a pure oxygen exposure at 25 fsw (1.76 bar) would be 49 min if a 2% risk of either symptoms or convulsions were judged acceptable. The level of



F6 Estimates of CNS oxygen toxicity risk based upon a statistical model (Vann 1988). The model was fitted to experimental data from 773 pure oxygen exposures which resulted in 11 convulsions and 33 incidents of symptoms. Exposures for estimated risks of 2, 5, and 8% are shown with the observed convulsions.



F7 The development and resolution of CNS oxygen toxicity risk according to the model during a multi-level dive on pure oxygen.

acceptable risk for a chamber dive where immediate rescue is possible after a convulsion is greater than for an open-water dive where drowning is the likely outcome.

Statistical modeling can track the resolution of risk as well as its development. In Figure F7, for example, a pure oxygen diver spends 120 min at 20 fsw, 15 min at 40 fsw, and 105 min at 20 fsw. His risk increases gradually to 0.2% while at 20 fsw and rapidly to 4.1% at 40 fsw. The maximum risk of 4.3% occurs just before surfacing after which the risk resolves in 10 min.

Unfortunately, the accuracy of the risk estimates of Figures F6 and F7 is uncertain because human oxygen exposure data are limited and their results variable. This uncertainty encourages conservative exposure limits, at present, instead of permitting the oxygen exposure to be adjusted continuously such that the estimated risk never exceeds the risk judged to be acceptable. For mixed gas, even less data are available than for pure oxygen, and the potential for carbon dioxide retention introduces further uncertainty which makes modeling of mixed gas risk even more problematic.

What Are "Safe" Oxygen Exposure Limits?

The choice of "safe" oxygen exposure limits depends upon the risk of convulsions that one is willing to accept. This subjective judgment is rendered all the more difficult because so few data are available from which to estimate risk and because there is so much variability in the response to oxygen exposure. Variability can be due to exercise, carbon dioxide retention, gas analysis error, oxygen setpoint control, and susceptibility to oxygen toxicity from inter- and intra-individual differences.

For air or enriched air diving, a maximum exposure limit of 1.2 bar would appear to be conservative while allowing a "cushion" for oxygen partial pressure increases due to unplanned depth excursions. Perhaps 1.4 bar would be acceptable if depth could be carefully controlled. On the other hand, there are those who testify to diving safely at 1.6 bar. This may well be true, but skepticism is appropriate until these divers document their claims in the form of computer-recorded depth-time profiles with certified breathing mixtures (F5). Denoble et al. (1993) describe a project and data acquisition software which might help to provide such documentation.

For pure oxygen, commercial and scientific experience suggests that at least 30 min of in-water oxygen decompression may be possible at 1.61 bar (20 fsw) with little risk of CNS toxicity. Experimental data (F4) also suggest a low risk at 1.76 bar (25 fsw), but a small depth excursion can cause large increases in oxygen pressure. **Pure oxygen diving at depths below 20 fsw is more hazardous.**

Improvements in our ability to manage oxygen exposure are expected as basic studies illuminate the fundamental biochemistry and physiology, as additional exposure data become available, and as statistical modeling methods develop. Basic studies have already led to pharmacological methods for extending oxygen exposure in mice, but further work is needed before such methods are applied to humans. The diving community itself can provide some of the necessary exposure data should it adopt a rigorous approach to data collection. Statistical modeling and computer tracking of oxygen exposure may eventually lead to guidelines for variable oxygen partial pressures to supplement single stage oxygen limits (F3). A particularly important advance that might eliminate much of the current unpredictability would be a mouthpiece sensor for measuring end-inspired and end-expired carbon dioxide. In the meantime, a patient and conservative approach to oxygen exposure management is appropriate to minimize the frequency of mishaps such as those of the past year.

A former Diving Officer with Underwater Demolition Team TWELVE, Dr. Richard Vann is an Assistant Research Professor in Anesthesiology and the Director of Applied Research at the Hall Center at Duke University Medical Center. He also serves as the Research Director of the Divers Alert Network. He can be contacted at: Box 3823, Duke University Medical Center, Durham, NC 27710, fax: 919-684-6002

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OXYGEN EXPOSURE MANAGEMENT ABSTRACT

Oxygen metabolism is the primary energy source in higher life forms, but when oxygen enters the metabolic process prematurely, reactive oxygen species can form which interfere with normal function and cause convulsions or other symptoms of oxygen toxicity. Immersion, exercise, and inspired carbon dioxide increase susceptibility to oxygen toxicity by elevating cerebral blood flow and oxygen delivery to the brain. The risk of toxicity is reduced by limiting oxygen exposure, but exposure limits are based on limited data. Limits for oxygen in mixed gas appear shorter than for pure oxygen. Open-water experience indicates that convulsions can occur near the accepted exposure limits. The risk of oxygen toxicity can be modeled statistically but with uncertain accuracy. The choice of "safe" exposure limits depends upon the risk of convulsions one is willing to accept. The maximum "safe" oxygen partial pressure for air or nitrox diving in the water appears to be in the range of 1.2-1.4 bar though some individuals set the limits as high as 1.6 bar. For pure oxygen, 1.6 bar has been used safely for in-water decompressions of up to 30 min.

VENDOR LISTING

Association of Dive Contractors	59
Amphibico	53
American Nitrox Divers Inc.	28
Back Country Eco-Tours	78
Beuchat	40/41
Blue Abyss	66
Carleton	81
Country Scuba	71
Cybertronix	66
Deep Inc.	51
DeRosa Villa/Aquatech	51
Dive Link	2
Dive Rite Mfrg.	84
Divematics	80
Diving Systems Int'l	25
Diving Unlimited Int'l	9
Farrallon	71
Flying Dutchman Hyperbarics	63
Gas Station	63
Ginnie Springs Resort	4
Global	37
Haskel	27
Heritage Foundation	73
High Tech Diving & Safety	78
IANTD	67
IANTD UK	67
Key West Diver	23
Lubrication Technologies	75
MiG Tech	73
Murray Dive	71
NSS-CDS	78
Ocean Odyssey	78
Ocean Mgmt Systems	21
ORCA	39
PSA	49
Quality Diver Education	78
Rebreathers for Sale	75
Repetitive Diver	31
RIX	60
Sea Dwellers	37
Sea Technology	57
Sub Salve	75
Team Vision	74
TBA	74
Underwater Applications Corp.	60
Viking	3
Working Diver	74
Zeagle Systems	15

INCIDENT REPORTS

South Coast of England

93JUL—An experienced wreck diver failed to surface following an air dive to 190 fsw/58 msw on the *Merchant Royal* and is assumed dead. The diver had become separated from her partner on the wreck who surfaced with the minimum required decompression and raised the alarm. Though visibility was excellent the body was never found during the ensuing two day search. The diver had been wearing twin 12 liter independent cylinders (about 200 cf) and a pony with decompression gas. She dived regularly to these depths and was reported to be a strong dependable diver.—*submitted by Simon & Polly Tapson, London, England.*

Sydney, Australia

93AUG—A wreck diver lost consciousness during a 15 minute **deep air dive** to 78 msw/254 fsw on the paddle tug, *Koputai*, and drowned. The diver lost consciousness while returning to the anchor line after a 15 minute planned bottom time to make his ascent. Though his three partners attempted to ascend with the diver in tow, they were unable to maintain a regulator in his mouth and he subsequently drowned. The team preceded to lift the unconsciousness diver to 15 msw/50 fsw and released him to the surface. Surface support personnel initiated EAR and radioed for emergency assistance/evacuation. The diver did not regain consciousness and was pronounced dead a short time later. Though the Coroner's report has not been released, CNS toxicity (working PO_2= 1.85 atm) compounded by possible CO2 build-up and narcosis—*characteristic of deep air dives*—is suspected as the primary causal factor. The incident raised government concerns about local deep diving practices. Though mix training has just gotten started in Australia, most deep dives are still conducted on air.—*Submitted by Richard Taylor, Sydney, Australia.*

Little River, Florida USA

93SEP—A novice cave diver ran out of gas and drowned on a solo dive in the Little River cave system. The diver was found with no air in either of his independent 104 tanks about 1300 feet back in the cave on the mainline. Though the individual frequently made solo dives he was not diving with a "buddy bottle."

The diver was known to use "creative" gas management rules outside of the basic tenets of cave diving and on at least one occasion had explained the gas management strategy he utilized to a group of cave students. Basically the diver reserved sufficient gas to exit from known points in the cave using the outflow in the system. The problem is that liberalized gas management rules such as this leave no margin for error or the unexpected compared to the golden "rule of thirds" or better (i.e use at least 1/3 of your gas for penetration and exit on the remaining two thirds).

Members of the recovery team speculate that the diver ventured into an unfamiliar part of the cave and got lost in the low silty tunnels and "tees." Having silted out the area, the diver spent precious time searching for the main line connection and likely missed the tee on the way back. Eventually he found his way to the line but it was too late. A long time aquaCorps subscriber, he had renewed his subscription only a week before.

Wakulla County, Florida, USA

93SEP—A very experienced 24 year old, cave diver lost consciousness and drowned while negotiating a restriction on the way back to the team's decompression stages following a deep mix exploration push to about 220 fsw/66 msw with a planned bottom time of 120 minutes.

The inbound leg of the dive which was the latest in a series of progressive pushes intended to connect several major sinks had gone as scheduled. The team of three reached the end of the line in good time and added about 800 feet of line (7800 feet back at about 220 fsw/66 msw) when the diver "unexpectedly" called the dive. The team turned for home. Upon reaching their staging area, the lead diver turned to see the diver tangled in the line struggling with his stage. The third diver freed him and they continued although the diver appeared shaken. As the diver negotiated the "short cut" restriction at about 200 fsw/61 msw and 2000 feet back, then his scooter prop caught and ate the line, halting his forward motion and pinned him between the floor and the ceiling just as his stage bottle ran out of gas. He flashed an "Out-of-Gas" signal to the lead diver who responded with his long hose. Thinking the diver was out of gas (he actually had 1000 psi in his 104s and 1000 psi in his other stage), the lead diver passed him a stage bottle. The diver gave back the long hose and jettisoned his old stage. At this point the cave silted up and the lead diver lost visual contact.

From the rear, the third diver saw his team mate wedged in the restriction and initiated touch contact as the cave silted out. The third diver squeezed his leg to indicate "Go" and the diver kicked. He backed off then squeezed again with no response. He tried to pry him free and at some point realized the diver was dead. The third diver unclipped his scooter and stage bottles and was able to squeeze around the unconscious diver in the cloud of silt and made physical contact with the lead diver.
Silted out and under the time constraints of their gas supply the remaining two divers linked up and motored back to the safety of the decompression bottles. The two had about six hours of decompression remaining.

The incident generated serious discussion in the cave community regarding the role of a dive team and how much push is too much. Reportedly the diver couldn't sleep the night before, had ill feelings about the dive, and exhibited anxiety. He told at least one person that this was the last of these dives he would do. It was reported that the diver was "off" that day and that he may have chosen to go ahead so as not to miss the "big" dive and lose status.

Honduras

93OCT—A novice deep diver lost consciousness and drowned during a "deep air" wall dive beyond 300 fsw/92 msw. The diver and his two partners, all experienced recreational instructors, were attending a combination charter and week long seminar on "Advanced Diving," and had been conducting progressively deeper air dives between 200-300 fsw/61-91 msw during the week. Though the boat apparently had a "YOUR ON YOUR OWN" policy, a mix instructor on the cruise made a "deep air" dive with the team to about 250 fsw/77 msw to check them out and give them pointers on their technique. He reported that *based on their skills*, he discouraged them from diving deeper. The captain was concerned as well. In fact a fourth diver associated with the team was reportedly asked not to dive deep or his trip would be curtailed.

The divers were utilizing dual independently rigged 80 cf cylinders and decompressing on air (oxygen was apparently not available). The dive was planned for five minutes to 300 fsw/92 msw using USN Exceptional Exposure Tables (to 300 fsw) with backup tables to 15 minutes. The diver was carrying a video camera to film the teams escapades and was the only member of the team with a decompression tool—a computer—for depths beyond 300 fsw.

According to one of the team, the group overstayed their planned bottom time by a minute or so and then the diver and one partner began to drift further down the wall (beyond 300 fsw). Having emptied his first cylinder "unexpectedly" (the divers did not switch regulators during the dive to balance their gas supply) and feeling that the dive "was starting to go wrong," the shallow member of the team executed a "*rocket ascent*" (of 100 fpm or more) that he had learned in the course to "*get out of the danger zone,*" and ascended to his first stop. Apparently moments later, the first diver lost consciousness somewhere around 325-350 fsw/99-107 msw. His partner began to haul him up using his BCD for added buoyancy when one of his single cylinders also ran out of gas. He lost his grip on the unconscious diver while switching regulators and due to buoyancy differences was separated from the diver. Short on gas he ascended and survived. The diver's body was never recovered off the wall. He was survived by his wife and four month old child.

Pompano Beach, Florida USA

93OCT A diver experienced what appeared to be the first onslaught of a CNS oxygen toxicity hit during an air dive to 228 fsw/70 msw on the *RV Johnson*, was able to make a rapid ascent to about 105 fsw/32 msw and survived. The diver and two others descended towards the wreck in order to set the anchor. Missing the wreck, and being deeper than they had planned, the divers began a hard swim at at about 228 fsw/70 msw (PO2 =1.66 atm) for about five minutes out of what was planned to be a 10 minute bottom time. He reached the mast at 190 fsw and tied off the anchor.

As he was working he got a severe pain in his molar, his lip began twitching and his jaw started chattering. Feeling a convulsion coming on, he held his regulator in his mouth, tried to signal to his partners and hit his BCD inflator just as he began to lose his vision and experience a mild convulsion. The symptoms began to clear during the rapid ascent and he was able to regain control at about 115-120 fsw/35-37 msw and stopped himself at about 105 feet/32 metres. The diver was then able to pull himself together. He completed his scheduled decompression and included a 20 fsw/6 msw oxygen "hedge" stop on EAN 80 (80% O2, balance N2). He surfaced without incident. An extenuating factor may have been the prescription decongestant, Entex LA. The drug had been used by the diver at recommended doses during the preceding week of diving. He had previously bought a regulator retaining but "forgot" to bring it that day. According to the Divers Alert network (DAN) there is no data to link the drug to the incident.

High Springs, Florida USA

93OCT—An experienced cave diver lost consciousness at the start of a "pleasure" cave dive at Devil's Ear and drowned. The dive was intended to be a fun dive to practice scooter techniques. The team of two mounted their double stage bottles and scooters and descended into the "Ear" against the normal outflow. The lead diver went through the first restriction after exchanging OKs with his partner. The diver appeared preoccupied. The lead diver got to the "Lips" about 200 feet into the cave, turned and waited. The diver wasn't there. Not seeing his lights, he turned and back tracked. He found the diver unconscious with his regulator out of his mouth in about 30 to 40 feet of water. The diver was immediately brought to the surface, CPR was initiated and the diver was flown to Shands Hospital. The diver was placed on life support but never regained consciousness and was pronounced dead the following morning. The Coroners report didn't shed light on the cause of his trauma. He had no history of heart problems, no predisposing medical conditions and no signs of embolism. Individuals can only guess that the diver had a serious problem, turned to exit following the floor of the cave, missed the exit, lost consciousness and drowned.

Please forward any technical diving incident reports to:
a.c: PO Box 4243, Key West, FL, 33041 USA
1.800.365.2655 f: 305.293.0729

Remember, you are responsible for your own safety. Never permit over-confidence, peer pressure or economics to allow you to compromise safety procedures. It could ruin your whole day.

Getting Insured

Spearheaded by vice president, Bret Gilliam, the International Association of Nitrox and Technical Divers, IANTD, a company specializing in technical dive training including deep air, nitrox and trimix diving, has secured insurance for their instructors. The policy covers teaching and supervision but does not provide coverage for the facility, mixing operations or recreational training. Similar to the insurance offered by the National Association of Underwater Instructors, NAUI, IANTD's policy covers all sanctioned teaching activities of the organization and is provided by the same carrier.

According to IANTD's broker, Peter Meyer of Jardine Rolfe Ltd., who placed the insurance, "the key to the policy is that IANTD students are primarily very *experienced* divers hence the risk associated with *entry-level* students is minimal. [In recreational diving], *diving class losses* are very hard to justify because of the the solid link between the instructor and the student. This is presumably not the case in technical diving, where students are presumed to be very qualified divers—in some cases more experienced than most [recreational] instructors—and do not require that someone take care of them. From an insurance perspective, the risks for this type of training are less." *(My understanding was that Meyer was referring to "the risk of insurance loss" should an accident occur and not referring to the dives—ed.)*

With regards to cost, the policy runs about the same as that of a open water recreational instructor at an annual premium of about US$ 460 and provides a million dollars of coverage. There is no deductible and no aggregate for claims. According to Meyer, though it is believed that insurance losses should be less, "there is no published data on losses for this type of diving activity." In the absence of other pricing benchmarks, the carrier agreed to write the policy at the same price as sport diving instructor insurance and "give it a year to see."

Meyer said that pricing of insurance policies is done on a profit and loss basis. The insurer estimates how many policies will be sold (the revenue), subtracts expected losses and administrative costs and then decides if the projected profit makes the policy worthwhile. Though the potential subscriber base for IANTD's technical training insurance is much smaller than that of recreational diving (probably about an order of magnitude or more less than NAUI's), it is expected that the loss rate will be proportionately lower as well, making the policy viable.

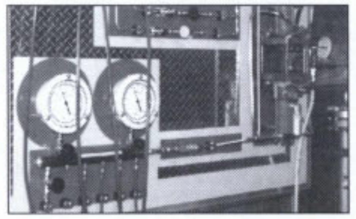
The good news is that there have been no training fatalities to date. And no legal actions have been taken against any technical diving instructor, many of whom have operated without insurance. The bad news is this may not always be the case. According to defense attorney, Bill Turbeville of Hruska & Lessor, "Now that they have insurance in place they should count on getting sued." Legal narcosis take two.—M^2

The American Nitrox Divers (ANDI) also offers full insurance coverage for it's instructors, divemasters and facilities for all of the ANDI programs including gas blending and trimix. Instructor insurance runs about $480 per year.

GREASER

ANDI is importing an alternative to toxic chlorinated solvents used in O_2 cleaning. **C12** is a biodegradable **non-toxic** low foaming detergent that provides an alternative to TCE and TCA solvent de-greasers. Made by Selden Research Ltd., the concentrate reportedly dilutes well, can be used in ultrasonic cleaners and is fully recyclable.

For more information contact ANDI @ 516-546-2026.



DEEPUNDERGROUND DEEPUNDERGROUND DEEPUNDERGROUND

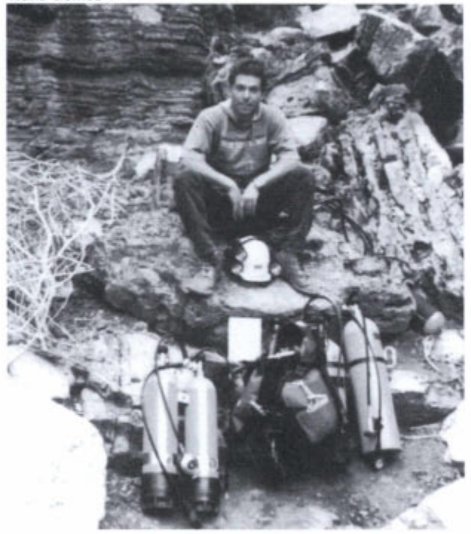
Sheck Exley

Max *Head* Room

On 10AUG93, a joint South African/US team of divers led by Charles Maxwell became the first to reach the bottom of a huge underwater cave at **Bushmansgat, South Africa,** at a depth of 863 ffw (feet of fresh water)/257 msw. The expedition also surveyed much of what is clearly the largest underwater cave room yet discovered. The team included Maxwell, biologist and cave diver Andrew Penney, and Africa's two top deep divers, Nuno Gomes and Boetie Scheun. From the U.S. came Alan Riggs, USGS hydrologist, and dive leader of the two deepest US cave diving expeditions to date, and Sheck Exley. Gomes had previously made the deepest descent in the cave (to 500 ffw/149 msw), and sounded the depth beneath the cave entrance using a shot line.

The upper 330 ffw of the cave was surveyed using a side-scan color imaging sonar operated by Barry Pardey of Overseas Technology (Pty) Ltd. Sections revealed a vast chamber that rapidly expanded with depth, reaching a maximum length of 820 feet and width of 230 feet at the 330 ffw depth level. Dives revealed that the pronounced overhand continues to even greater dimensions below. The estimated volume of the single room, entered by a three by ten foot crack in the ceiling, is at least 156.2 million cubic feet, or almost four times the size of the next largest known underwater room, Dean's Blue Hole in the Bahamas. Only three air-filled rooms in Malaysia and New Guinea are larger. Future investigations will probably reveal that Bushmansgat is larger than at least two of those rooms. The deepest dive (863 ffw) is second only to Exley's 1989 descent to 867 ffw at Mante, Mexico. The maximum depth of Bushmansgat will probably be found to be considerably deeper, since the dive was made almost directly beneath the surface opening, on a sloping bottom.

Nuno Gomes



All deep dives were conducted using DR. X's software based on the A. Bühlmann ZHL-16 algorithm and Exley's dive planning algorithms. Some special problems encountered were the high altitude of the site at over 5000 feet above sea level. No DCI symptoms were reported on any of the dives.

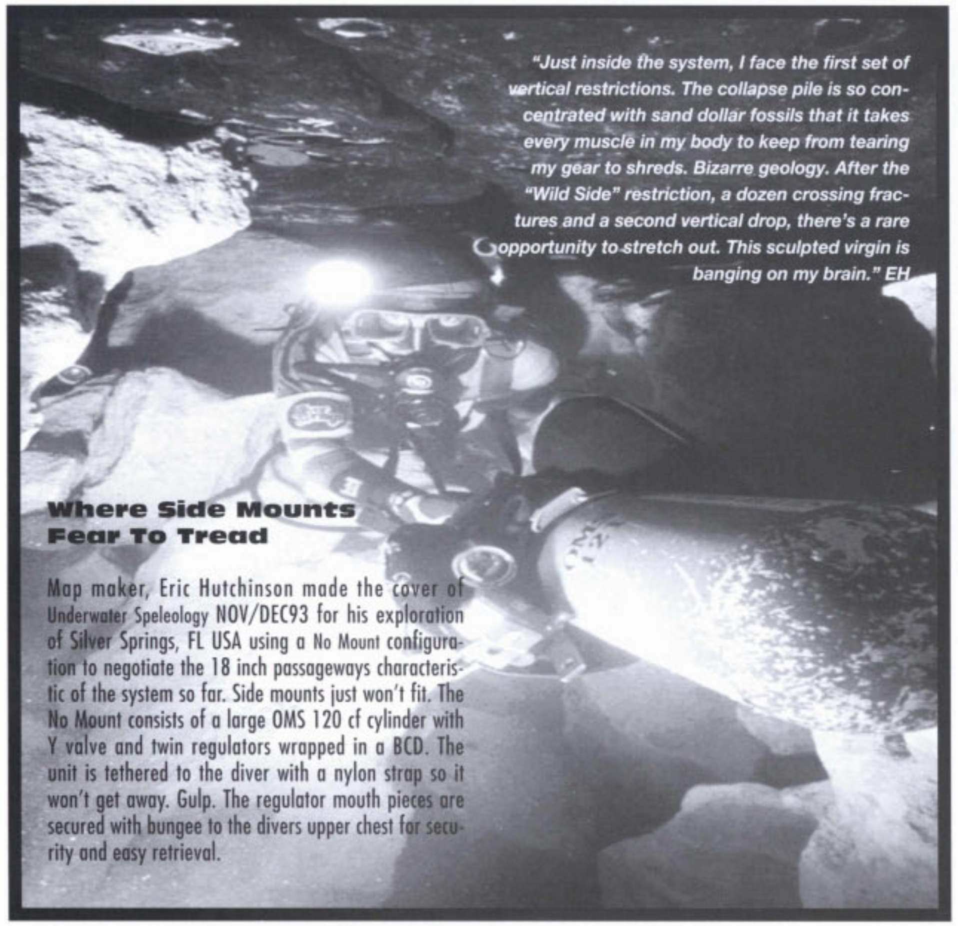
Perhaps the most interesting aspect of the dive was the occurrence of High Pressure Nervous Syndrome (HPNS) reported by Exley below 700-750 ffw 209-224 msw. Following a descent rate of more than 100 fpm to that depth, the diver reported that the first symptoms were visual disturbances—his entire field of vision becoming a series of small congruent circles with black dots in their centers. Distance vision also appeared to deteriorate, objects appearing to blur. Less than a minute later and 30 to 50 ffw deeper, the diver reported itching all over his body, quickly becoming a rather painful stinging sensation. Slowing the descent to 30 fpm to forestall the HPNS, the diver reported the onset of tremors, which increased until reaching the bottom at 863 ffw. All symptoms disappeared during a 100 fpm ascent to the first stop at 400 ffw/119 msw. It is not yet understood whether the HPNS was the result of the rapid descent rate or insufficient narcoticization. The END (equivalent narcotic depth) for the dive was 260 fsw. Gomes who reported HPNS tremors on a previous dive to 500 ffw/149 msw, encountered no symptoms when he dived to 551 ffw/164 msw on this project.—*submitted by Sheck Exley, Live Oak, FL USA*

Ann Kristovich

The Pits

On 2SEP93, at the base of the Sierra de Tamaulipas in northeastern Mexico, members of the *Proyecto de Buceo Espeleologico Mexico y America Central* conducted a series of deep dives at a site identified as Pit #6350. The dive made by Dr. Ann Kristovich set a new women's depth record of 554 ffw/165 msw surpassing the previous record of 400 ffw/119 msw established in 1989 by Mary Ellen Eckhoff at the Nacimiento, Mante. The second dive of note was made by *Proyecto* leader Jim Bowden to a depth of 744ffw/231 msw. This places Bowden second only to team member Sheck Exley who holds the current men's depth record at 881 feet/263 msw.

Both dives were conducted on trimix using Dr. X software. Kristovich utilized trimix 9/55 (9% O_2, 55% He, 36% N_2) as a bottom mix. Air was used as a travel mix to 280 feet/and for decompression beginning at 260 feet/ 77 metres to 70 ffw/21 msw. EAN 50 (50% O_2, bal. N_2) was used from 60 to 30 feet, followed by pure oxygen. Her total decompression time was approximately 225 minutes. Bowden used trimix 8/60 (8% O_2, 60%He, 32% N_2) as a bottom mix. Air and trimix 11/50 (11% O_2, 50%He, 39.5% N_2,) was used as intermediate travel mixes, followed by EAN 50 (60 to 30 ffw) and oxygen for decompression. Total decompression time was approximately 280 minutes. Members of the Proyecto have logged more than 121 dives in this very unique system. No symptoms of DCI or other hyperbaric problems have been experienced by any of the team. *Proyecto* members will be returning to Mexico later this year to continue the deep exploration of this system.—*Submitted by Jim Bowden, Austin, Texas USA.*



"Just inside the system, I face the first set of vertical restrictions. The collapse pile is so concentrated with sand dollar fossils that it takes every muscle in my body to keep from tearing my gear to shreds. Bizarre geology. After the "Wild Side" restriction, a dozen crossing fractures and a second vertical drop, there's a rare opportunity to stretch out. This sculpted virgin is banging on my brain." EH

Where Side Mounts Fear To Tread

Map maker, Eric Hutchinson made the cover of Underwater Speleology NOV/DEC93 for his exploration of Silver Springs, FL USA using a No Mount configuration to negotiate the 18 inch passageways characteristic of the system so far. Side mounts just won't fit. The No Mount consists of a large OMS 120 cf cylinder with Y valve and twin regulators wrapped in a BCD. The unit is tethered to the diver with a nylon strap so it won't get away. Gulp. The regulator mouth pieces are secured with bungee to the divers upper chest for security and easy retrieval.

T1: Comparison of Sub-Foot (150 m) Technical Dives

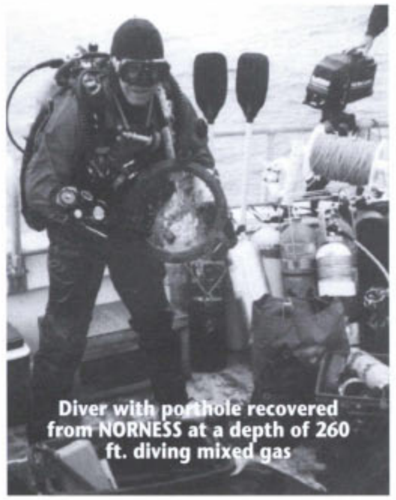
Beyond 500 feet (150 m)

Table, T1, summarizes the 13 self-contained technical dives that have been successfully conducted to date beyond 500 feet (154 msw). All of these are cave dives, though the open water community is not too far behind. All dives except King's blue hole descent were conducted in fresh water. No DCI symptoms were reported other than general fatigue—not surprising after such long dive times—and a single case of skin bends. HPNS was reported on two of the dives, both at Bushmansgat, South Africa: Gomes' 1992 descent to 500 ffw/163 msw, and Exley's recent descent to 863 ffw/257 msw. Reports of HPNS will probably increase as the technical diving community makes more helium dives to depths below 400 feet/123 metres due to the rapid descent rates.

The water temperature for the dives varied considerably. Coldest by far was Vaucluse, 55 degrees F. (13° C) Next is Bushmansgat, at 66 degrees F (19° C), followed by Mante at 78 degrees F (26° C). The warmest dive was Bowden's 170 Fathom Grotto, at a very pleasant 87 degrees F (31° C).—submitted by Sheck Exley, Live Oak, FL USA

* Note that the bottom mix on these dives were blended by topping a fixed amount of helium with air, a convenient field mixing practice for remote locations.

Date (mm.yy)	Depth (ffw)	Diver	Location	Bottom (time)	Runtime (min)	Table	Bottom Mix	DCI
9.83	656	Hasenmayer	Vaucluse, France	0:??	9:00	Oceaneering/JH	Trimix ??	none
4.87	520	Exley	Mante, Mexico	0:15	7:30	Oceaneering/Exley	Trimix 11/50*	none
6.87	660	Exley	Mante, Mexico	0:24	11.13	Oceaneering/Exley	Trimix 8/60*	rash
4.88	780	Exley	Mante, Mexico	0:24	10:43	Hamilton	Trimix 7/69	fatigue
3.89	867	Exley	Mante, Mexico	0:24	13:30	Hamilton/Exley	Trimix 7/69	none
??.92	500	Gomes	Bushmansgat, SA	0:06	3:00	Bühlmann/Gomes	Trimix 11/50*	none
9.92	683	King	Dean's Blue Hole	0:11	5:24	Hamilton	Trimix 8/70	fatigue
4.93	721	Exley	JB's 170 Fathom	0:07	4:58	DR.X	Trimix 11/50*	none
4.93	503	Bowden	JB's 170 Fathom	0:05	4:00	DR. X	Trimix 11/50*	none
8.93	863	Exley	Bushmansgat, SA	0:13	6:50	DR. X	Trimix 7/66*	none
8.93	581	Gomes	Bushmansgat, SA	0:06	4:00	DR. X	Trimix 11/50*	none
9.93	744	Bowden	JB's 170 Fathom	0:11	4:42	DR. X	Trimix 8/60*	none
9.93	554	Kristovich	JB's 170 Fathom	0:07	3:45	DR. X	Trimix 10/54*	none



Dinosaurs?

That's what Lalo Fiorelli and Lee Racicot of Northern California wondered after concluding a 214 minute, **ten thousand** foot swim with three stages and doubles at about 42 feet/13 metres in Sac Atun, Yucatan Mexico. Besides the **ten bottles** shown, the team decompressed on O_2 from a 50 cf bottle. Is this the future of self-contained diving? **Take another breath...**

Photo by Fiorelli Diving & Photo

Floating ART

The *Andrea Doria* has often been described as a floating art gallery, and justifiably so. The greatest artists in Italy were commissioned to grace the luxury liner with their paintings, murals, copper reliefs, and ceramic panels; precious works of art that were lost to human consciousness when the ship sank irretrievably in 240 fathoms (74 meters) of cold Atlantic water.

But the summer of 1993 saw at least two of those precious works of art emerge from the depths. In July, John Moyer led an expedition of high-tech divers who salvaged two ceramic panels which were each five feet wide, six feet tall, and weighed over 700 pounds. They were recovered from the port Wintergarden on the high side of the wreck, from a depth of 185 feet/57 metres.

The ceramic panels were created by Guido Gambone, an Italian artist whose cubist style was patterned after the work of Picasso. Each panel contained three or four smaller, segmented panels that were embedded in a matrix of cement and surrounded by maroon tiles. The scenes depicted are bizarre representations of people, animals, and one creature that has the body of a man and the head of an antelope.

Although difficulties were encountered in dragging the heavy panels along the corridor under inflated lift bags, the most difficult job was getting the one-third ton artifacts from the surface to the boat using people power; there were no pulleys or winches. It then took a crane to get the panels off the swim platform and onto the dock.

The panels are currently undergoing preservation treatment. They are remarkably well preserved. Eventually, Moyer hopes that the panels find recognition in the art world, and perhaps a place where once again these lost art treasures can be displayed for public viewing.—*submitted by Gary Gentile, Philadelphia, PA*

continued from page 32

the civilian marketplace at this time simply because we don't see a large enough market to support the cost of liability coverage nor is there a training network in place to satisfy the risk involved with this type of life support equipment. I would rather be the follower than the leader at this time. **However I do see potential in the law enforcement market. There's a lot of similarity between police and military divers and they also have fairly controlled training. "**
Ken Greene, Vice president, Carleton Technologies Inc.

Plunk down

"I've been fortunate enough to work with the people producing prototypes and we have access to the equipment. We're currently doing evaluation work with those manufacturers. **The equipment is far and above anything that we've been able to do with open circuit trimix.**

I do think the market is going to develop though it's a high risk situation for private investors. The liability issue needs tremendous consideration and the costs have to come down. **However, once we get some history regarding how well this equipment works, not to mention the safety factor of closed circuit—*people won't die because they ran out of gas*—I think everybody will jump on the bandwagon.** Right now however, it's a chicken-and-egg syndrome. The money's not there to do the work to sell it to the general public and the general public's not going to buy a pig in a poke. As a result, it's likely going to take someone already entrenched in the market that has the capital, the name, and the distribution and training facilities to bring this equipment out. The barriers to entry for an unknown upstart company are horrendous.

Of course for individuals that are really motivated, there's no reason they couldn't own the equipment right now. **I assure you, if you're willing to plunk down enough money, the people who have the equipment will sell it to you once you're properly trained."**
Jim King, President, Deep Breathing Systems

When?

Everybody's asking that question, including all of us at Cis-Lunar. We get up in the morning and shave and say, "When?" I'd rather pose the question to your readers—it's up to them. They're the ones who are going to have to make the decision as to whether or not this thing needs to happen. The technology exists today, but it doesn't appear that the complex business environment in which we operate is ready. **When the community really starts to feel strongly about closed circuit and really wants to push for it, then it's going to happen.** Will it be next year? No. Will it be in two years? Maybe. Within five years, someone will be bringing closed circuit technology to the consumer marketplace.
Richard Nordstrom, CEO, Cis-Lunar Development Labs

Driving Force

"Closed circuit technology is not very different than the enriched air. The first thing that has to happen is you need product and a thorough training program. **The second thing that has to happen is that dive stores have to get behind it. In spite of what many pundits would say, nothing happens in this industry [sport diving] if it doesn't happen in the dive store first.** The full-time professional dive store is the heartbeat and lifeblood of the industry. That's where all the merchandise is sold.

To actually drive the technology, you need sales volume and the sales volume is going to have to come from the bigger diving market. That's why the people that are smart are saying, "How many people can I sell it to?" and thinking it through. **Ultimately the driving force is going to be the recreational market, and from there, there will be enough money leftover to play with the high-tech stuff.**

I envision a major US company, most likely Oceanic, and a major Japanese company involved in this market. The Japanese are very, very recreational oriented not to mention technology and manufacturing driven."
Ed Betts, President, American Nitrox divers Inc.

Note that during it's 93DEC UK dealers meeting, **Oceanic** told attendees that it would be introducing several rebreathers in the UK in 1994. Reportedly they will have a prototype at the 1994 DEMA show. Meanwhile a Japanese company, **Grand Bleu Inc.,** has already announced its plans to build and market a limited capability semi-closed system for recreational divers and has retained several US consultants to help. M^2

tek.TERMS

Absorbent: The chemical material such as soda lime or lithium hydroxide used to remove the CO_2 in the breathing circuit.

Breathing bag: The flexible bag inside the unit that allows the diver to breathe in and out. See counterlung.

Bypass valve: Manual controls on the diluent and oxygen gas supplies that allows the diver to fly the system manually in the event of a crash.

Bubblers: Open circuit scuba divers.

Canister: The component of a semi or fully closed circuit rebreather that contains the chemical CO_2 absorbent.

Cheap: What gas fills are for a rebreather.

Cocktail: AKA "caustic" cocktail. Breathing in a solution of CO_2 absorbent that has come into contact with water as a result of flooding the canister. This is less of a problem in modern systems.

Constant mass flow valve: A regulator used in a semi-closed circuit system to deliver a constant mass of premixed gas to the diver independent of depth.

Constant PO_2 table: A decompression schedule based on maintaining a constant partial pressure of oxygen. Next generation rebreathers will have onboard decompression computers.

Consumables: The materials that are "consumed" during closed circuit diving operations including gas supplies, the chemical absorbent used to remove the CO_2 in the breathing circuit and batteries. Typically this amounts to a few dollars of gas and perhaps $10-20 of absorbent depending on the dive(s).

Counterlung: The flexible bag inside the unit that allows the diver to breathe in and out.

Cryogenic scrubber: A next generation CO_2 scrubbing concept that freezes out the CO_2 in the divers breathing loop using a super cooled refrigerant. First used in the Sterling Electronics SS-1000.

Deep, hard and not often enough: You tell us.

Diluent: The carrier or make up gas used to dilute the oxygen in a C2 system to keep the PO2 within physiologically safe limits and to maintain the ambient pressure in the breathing loop. Typically the diluent contains an inert gas component such as N_2, He or Ne mixed with sufficient O_2 to sustain the diver at the deepest portion of the dive in case of emergency.

F2F: Face to face.

Gas switches: Switching gas mixes during decompression in order to improve decompression efficiency and reliability.

Heads up: A warning light display used in the Carleton Mk-16, Cis-Lunar Mk-4 and other rebreathers that is mounted in front of the divers face mask. Information displayed includes PO_2, sensor and battery status. Note that none of the systems in development offer true "through-the-mask" heads up systems.

In The LOOP: Where you are if you subscribe to *aquaCorps Journal*. Take another breath.

KYAG: What you should do if your rebreather craps out and you don't know how to operate it properly.

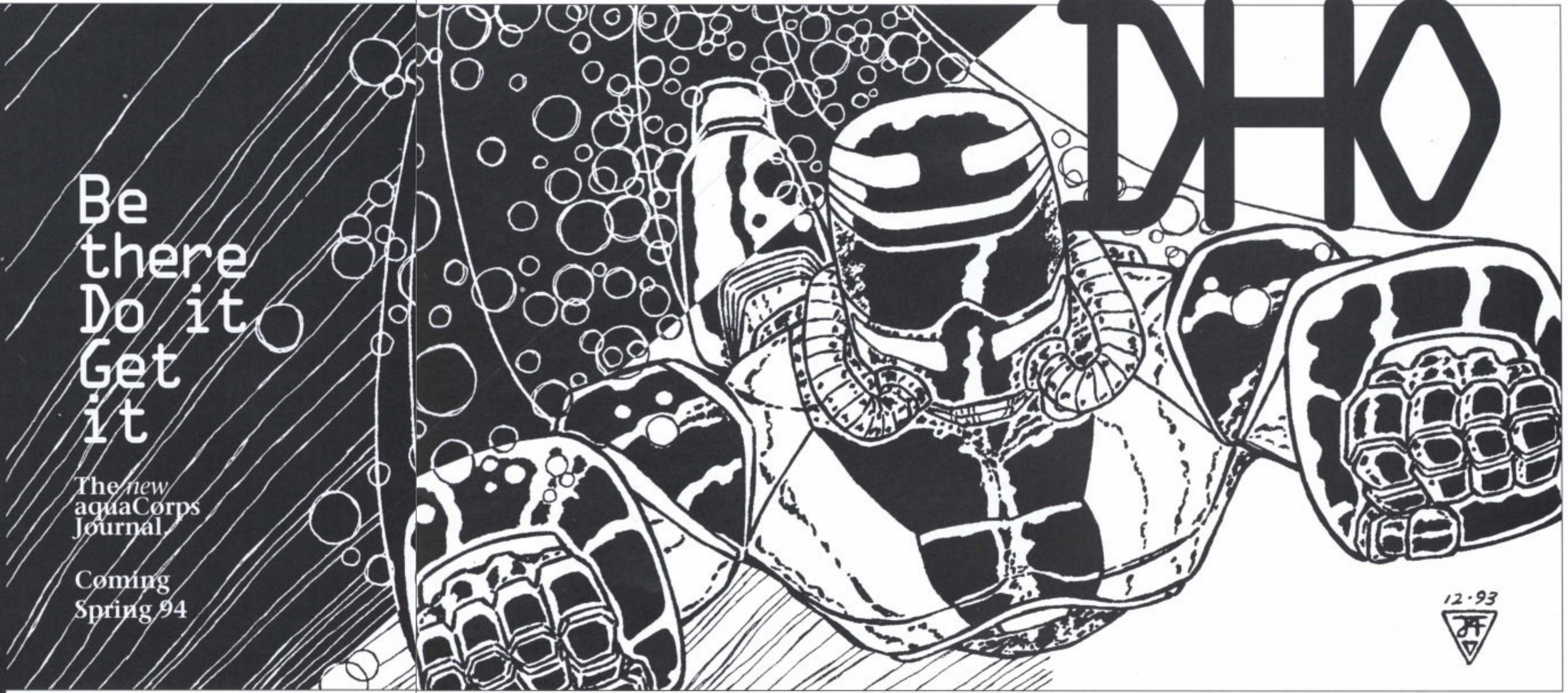
Membrane scrubber: A next generation CO_2 scrubbing concept that utilizes a molecular sieve to selectively remove CO_2 molecules from the breathing loop. Carleton Technologies currently is working on an operational unit.

Mixing on the fly: Slang for on e of the key features of a closed circuit rebreather i.e. onboard mixing.

Scrubber: The component of a semi or fully closed system that removes CO_2 from the breathing loop.

Set point: The preset partial pressure of oxygen (PO_2) to be maintained by a closed circuit system. Note that some of the newer systems allow the user to vary the set point during the dive.

Stack Time: The "canister" time remaining on the Cis-Lunar Mk-4 rebreather. In Cis-Lunar lingo a canister is called a "stack."



Corps.SPACE

continued from page 5

ground reservoirs, mediation is impossible.

Please ask all members of the technical diving community to write or call Florida Governor Lawton Chiles, Florida's Secretary of Environmental Regulation, Virginia Wetherell, and the corporate offices listed below to **express our grave concern and to seek a complete factual environmental impact study for this pipeline and storage facility.**

Christopher A. Brown
National Association for Cave Diving
Tallahassee, FL

CALL OR WRITE TO:

Governor Lawton Chiles
Office of the Governor
The Capitol
Tallahassee, Florida 32399-0001
(904) 488 - 4441

Ms. Virginia Wetherell, Secretary
Office of the Secretary, Rm. 2600
Department of Environmental Regulation
2600 Blairstone Road
Tallahassee, Florida 32399-2400
(904) 488 - 4805

Mr. James W. Kinnear
President and Chief Executive Officer
Texaco, Inc.
2000 Westchester Avenue
White Plains, New York 10650

Heat Loss Revisited

A lot of people think that they will become cold much faster if breathing a helium mixtures instead of air. You can find this myth perpetuated in "MIXED GAS DIVING'" by Gilliam, Mount et al (page 87) and in IAND's "Technical Nitrox Manual" (page 191), both printed in 1993. The authors state that it takes 125.2 cal to heat up (10°C) 100g of argon, 343.9cal are required to heat 100g of air 10°C, and 100g of helium requires 4968cal. Their conclusion is that breathing helium mixture increases heat loss. The thermal capacity constants, c_p, for air and helium are also given incorrectly. The stated helium value of 4.968 looks more like *Joule/(g°C)* units than *cal/(g°C)* units (conversion factor is 4.186). The correct value for helium is 1.25cal/(g°C). The value for air should be 0.2398cal/(g°C) not 0.3439 as stated.

Heating up 100g of argon by 10°C does require 125.2cal, however the correct amounts for air and helium are 240cal and 1250cal respectively. Helium does require far more energy but there is a mistake in the calculation. As a diver, I don't care about how many grams or pounds I fill into my lungs or dry suit; those are *mass* or *weight* units. Lungs and dry suits however are filled to a certain *volume*. Note that 100g Helium has a 7.6 times larger volume than 100g air (at the same pressure) due to the large density difference. Therefore in order to determine the correct heat loss, the amount of heat per volume must be calculated. Now let's see how much energy it takes to heat up a certain volume.

I use 2 liters (0.07cf) for the calculation in order to derive the energy needed per breath to heat up the breathing gas by 20°C from water temperature (17°C = 63°F) to body temperature (37°C = 99°F). Two liters of air have a mass of 2l x 1.293g/l = 2.586g, two liters of helium have a mass of 2l x 0.17g/l = 0.34g. The energy needed to heat up the air is therefore 2.586g x 0.24cal/(g°C) x 20°C =12.4cal. To heat the same volume of helium 0.34g x 1.25cal/(g°C) x 20°C = 8.5cal. This calculation shows that the heat loss even from breathing pure helium (don't do it) would be 32% less than breathing air.

This result would be also true for the dry suit, however here another factor comes into play—thermal conductivity. The thermal conductivity for helium is about six times higher than that of air. That's the reason there is substantial heat loss if the dry suit is filled with a helium mixture. The heat *transport* from the body to the surrounding gaseous medium is high. That's also why argon is a good suit inflation gas because its thermal conductivity is about 33% less than that of air. (See *"The Case for Heliox"* by Dr. Bill Stone, a/c J N4, Mix, January 1992.) Thermal conductivity in the lungs is no problem because the heat is only transported from one end of the lungs to the other inside the body. It is only responsible for the cold *feeling* in breathing helium mixtures because the heating process is faster at the *beginning of the breath*.

Bernd 'Aschi' Aspacher
Gainesville, FL USA

Risk Assessment

Technical divers know the risk of hyperbaric incidents are dramatically higher when they conduct dive operations outside of the traditional recreational envelope.

I recognize that none of us are going to suspend dive operations because we don't have a chamber, but perhaps **we should**. Similarly, the number one equipment requirement for a gas dive should probably be a full face mask. Review the accident statistics of the last 18 months. Many of those who died did so because they could not tolerate a regulator in their mouths and would likely be alive today if they were wearing full face equipment. Ignoring this safety equipment may be as grand a mistake in judgement as violating the rules of accident analysis in the cave environment. It is time we bring our zeal for the allure of these dives into context with the reality of the risks facing us.

Lalo Fiorelli
Soquel, CA
USA

The Technical Revolution 2.0

"An experienced diver wearing double over pressurized 72's ran out of gas..."
"An experienced diver drowned after getting separated from the mainline..."

The list goes on. After a while people become desensitized. Incidents become abstract adventure lessons for everyone but the family and friends—proof of the dangers of technical diving. You can scream "SAFETY FIRST" all year long, write warnings, follow guidelines, take courses and sincerely work to improve safety, however, the cold truth is that you're scarcely going to improve technical diving safety at all because the system itself is rotten to the root. Technical diving needs a revolution. A furtherance of the status quo will likely only lead to more grief, followed by governmental regulation.

Who am I to talk? I come from a place where sugar doesn't get you anywhere, except maybe dead. I don't have a grand scheme. I'm just a commercial diver writing about a wrong that I have a long shot at righting. I don't have all the answers, but I have enough of them to guarantee that if technical divers followed my advice, their accident rate would plummet and their capabilities would be greatly enhanced. So here it is.


CURT BOWEN

First, you need at least a two-point mooring system for your boat to stay on location. Three-point is noticeably better. A buoy mooring system will work. For wreck diving, a neutrally buoyant umbilical would provide unlimited gas, communications, and a line system that you can't lose. Diver to diver and diver to surface communications are critical.

The good news is you will likely never run out of gas when using an umbilical. If you do, you've got your bailout bottle and comms. Just say, "I'm presently out of breathing medium. Would you be so kind as to supply me with a new source of gas, preferably one containing oxygen." This beats the hell out of drowning. If you get tangled and overstay your decompression welcome, you can work it out with comms and an unlimited gas supply. The boat will always be at the end of your umbilical which will lead you back. Use a full face lightweight mask, or even a dry hat. You'd be surprised at how much warmer you stay on a gas dive with a dry head. For colder climes a hot water machine and thermal jacket are just the ticket. Obviously you need a highly trained topside crew to run all this. Most likely you'll need a bigger boat.

"You mean I gotta dive a hose?" Get over it. The umbilical is freedom, not restraint. It's just a line, only better. You can live with it. Think of all the gear you don't need to carry, on and under the water and don't forget the packing and clean up. All the pressure of time and decompression is transferred to the surface. Relax and enjoy it. Think about hot water in the decompression bell and the emergency refuge it supplies.

A lot of education and work is required to dive a modified commercial system but it may well be worth it in lives and injuries. How expensive is it? Not as much as you might think. An individual set of technical diving gear is quite expensive, however, in the commercial system the expense is in the trip. The boat owns the gas rack, the bell, the radios, the compressor, the hoses, hot water, helmets, bailouts, etc. Bring your personal gear and prepare to pay a hefty rental fee. If you have your own boat it will cost you less than $25,000 to outfit and quite a bit less if you can put it together yourself.

You've been working too hard, my friends. There is a better way, perhaps the only real future technical diving has. Let's work it out together with some give and take.

Bob Ibzepski
Editor, *Working Diver*
LaCombe, LA USA

Deep Diving Forum

If technical diving is to reach its potential then collectively our society needs to support the development of its own infrastructure. It is incumbent upon all of us within this society and for those who are attempting to "do it" to keep their motives pure and for the rest of us to support them without hesitation. We need to accept and establish room for honest differences of opinion and be able to set differences aside at times to work for the common good of all. The commercial dive industry went through this same challenge when it first started, however they were fueled by the economic need of the oil industry. There is no pressing economic need in our pursuit, only the essence of man's inquisitive nature to explore.

We have a number of challenges facing us in the future. Among them we need to establish, agree upon, and publish the operational procedures and qualifications as stated in the **Deep Diving Forum** in January 1993. This has been started and now needs wide distribution and endorsement of everyone who agrees to them. I believe it is important that divers understand how vulnerable this new art form really is. Governments could easily restrict your rights, deny you access. Boats could be forbidden to take you where you want to go, equipment suppliers forced out of business, gas suppliers restricted from supplying. We must be careful and responsible.

Dick Long
President, Diving Unlimited International
San Diego, CA USA

Sensational Journalism

You tend to form an opinion on an issue, discuss it and report your opinion as fact regardless of documentation. You repeatedly state folks convulse, even though no one witnesses the convulsions. Yes in many cases we may think a person convulsed, but folks die from other causes. Without a witness you cannot state factually a convulsion occurred. You continually state dramatic activities for sensualism or whatever instead of saying "It is believed that the diver switched to oxygen [at depth] based on the psig reading of the oxygen bottle"—because the latter statement is all that is really known. Come on Mike, become a journalist not a sensationalist.

I do not know what you are basing the statement of "at least 50% helium will most likely become [a community] standard" [*for dives in the 250-300 fsw/75-90 msw range—END of 85-118 fsw/25-36 msw*]. The majority of folks, TRIMIX DIVERS, and INSTRUCTORS, I talk with, which greatly exceeds your input with this community, do not lean towards 50% though a select few do. Mike we track that information at IAND, we can state facts not opinions as you do.

Whether you believe it or not, YOU ARE NOT THE GURU OF TECHNICAL DIVING. In fact I do not believe anyone would qualify for that title.

We have another serious bone of contention. You have stated that there are NO STANDARDS AND PROCEDURES. IAND has had standards since 1991 and they have been updated and revised three times from field input. The standards are justifiably good that we now have got an insured diver certificate program based on these standards. If a risk management insurance feels that they are adequate they must be relatively good. We would greatly appreciate it if you would acknowledge the fact IAND does in fact have standards and procedures for technical diving, and get off this 'there are no procedures baloney.'

Tom Mount, President,
International Association
of Nitrox & Technical Divers
Miami, FL USA

Thank you for your feedback. I try to be as specific and accurate as I can in my analysis and try to label opinions as such. With regard to standards (Menduno, Trimix Report, a.c J N6,

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Computing), I stated, "On the training side, the International Association of Nitrox and Technical Divers, (IANTD) has pioneered the development of user and instructor trimix training programs..." *and,* " IANTD has made significant progress over the last year in developing training standards." *I think it is important to distinguish between teaching standards and guidelines for conducting operations (similar to the ADC consensus standards in commercial diving). Currently there are no published guidelines for mix diving operations to my knowledge, and in my opinion, we have a long way to go. Hopefully this clears the issue up.*

Misplaced information

Your continued rehashing of old accidents (*Trimix Report*, a.c J N6, Computing) that, materially, had nothing to do with mix gas usage hurts the technical community not only in the insurance market, but in the public perception of this type of diving. When divers die in wrecks because they ran out of gas or became lost, how does it matter that they were breathing mix? Likewise, when a Florida cave system collapses on some of the country's most experienced divers, how does it matter that they were breathing mix? Your misplaced information will be used against us by the likes of Skindiver, PADI and opponents who would seek to scare off our insurance underwriters.

Bret Gilliam
Vice President, IANTD
Bath, ME USA

Because of the typical exposure range involved (deep, long, decompression), mix diving is inherently dangerous. We would rather err on the side of caution and rehash recent events in hopes that we all can learn from them. Those that fail to learn from the past are doomed to repeat it. It's some kind of karmic law.

Graphic disturbance

I found several errors in *aquaCorps Journal* N6, "Computing." The most disturbing was the lack of indexing and a printing error with respect to the graph on the cover. Without proper annotation and indexing the graph on the cover is difficult, if not impossible to interpret.

1) Which axis represent risk, time and depth respectively.
2) In what units are they measured?
3) The cover graph and the "Total Decompression Time" graph (F1) appear identical. Which is it, the risk of decompression illness or decompression time? It appears that you may have made an error and printed the same graph twice.

I would very much appreciate receiving properly annotated and indexed graphs representing the two sets of data, as I am very interested in what I may derive from them. Can you help?

Bill Schmoldt
Brielle, NJ USA

Oops. The graph on the cover represents "risk of decompression illness." Risk, measured in percentage ranging from 0 to 45% at its highest point, is represented by the vertical axis. Bottom time ranging from 5-480 minutes runs from left to right across the page and depth ranging from 40-300 fsw (12-91 msw) is shown on the inward pointing axis beginning at the edge closest to the reader. You are right, the risk graph was mistakenly reprinted as Figure 1. Erratica. To obtain a copy of the original artwork and data sets contact: David Story, R& D Divers, 1016 East El Camino Real #501, Sunnyvale, CA 94087 USA. f: 415.967.8496.

Intellectual Stop

My husband and I were talking last night and we want to put in a request to aquaCorps. Can you print the Journal on waterproof paper so that we can have something intelligent to read on our stops?!!?

Susan Young,
Quabbin Divers,
Grand Cayman

Genetic Bent

Davina Menduno, 18 years old, recently received her PADI open water certification in London, England where she is pursuing her art career, plans to travel to India and go diving. What is a father to do? (:—>). M^2

Note that corps.space letters have been edited for brevity.

Do you have information to share with our readers?We invite you to communicate:

a.c, PO Box 4243, Key West, FL, 33041
USA 1.800.365.2655 f: 305.293.0729

Cyberspace Revisited

Delphi Computer Network has launched a new scuba forum which features information on travel, instruction, marine science, diving medicine and **technical diving.** Delphi is currently offering a **FREE five hour trial to aquaCorps readers** who sign up on-line using a special access code.

In addition to the forum, Delphi offers a full range of **Internet services.** Estimated to have more than one million online systems, Internet is the net of all computer networks (a series of linked computer systems). No one knows for sure just how large it is. And that is how it should be. (*It was reported that the Iraqians kept up to date on the war by jacking into Internet through the Universities.—ed.*). Internet allows people to communicate with electronic messages (e-mail). Unlike "snail" mail, your message will arrive in a matter of seconds to a few minutes. It is even easier to share ideas with a whole group of people through a facility called lists.

In addition to e-mail, the Internet provides access to vast amounts of information and offers a number of features to help you get it and share it quickly. One of these features is called Usenet. Usenet is what many people think of as a computer bulletin board system (BBS). Internet also offers a number of utilities which makes finding information easier. One service is called Gopher, because it can root out files in systems all over the world.

Although many commercial services offer Internet e-mail, Delphi offers users a full complement of Internet features including telenet, Usenet, e-mail, Gopher and IRC which is Internet's form of on-line chat.

To subscribe to Delphi (USA) and get a special **five hour free** trial follow the these instructions. Non-US readers contact your local Internet provider.

Dial by Modem, 1.800.695.4002
Press return once or twice
At the User name prompt,
enter: JOINDELPHI
At the Password prompt,
enter : CUSTOM121
Follow the instructions

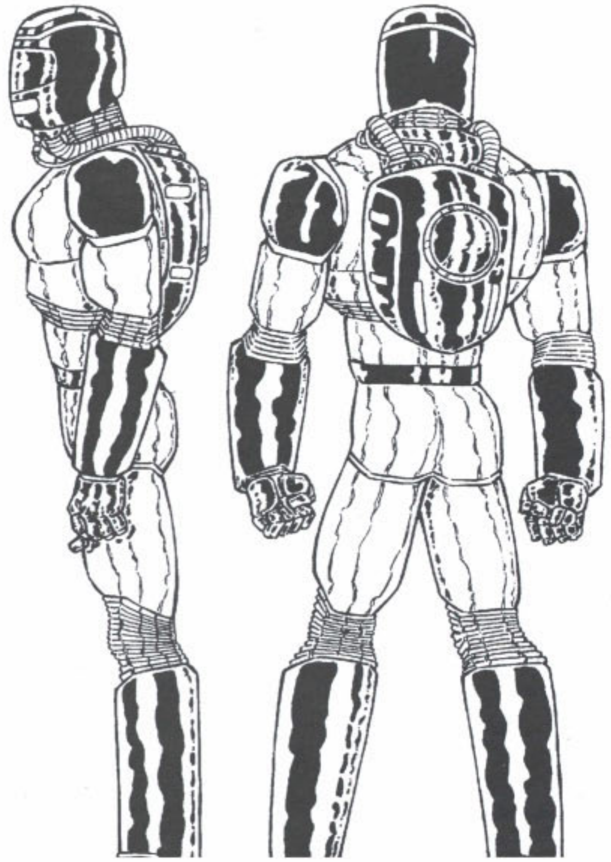
For more information contact Rick Williams at: POB 397, Newburgh, IN 47629-0397 USA, p: 812.858-0333 or via e-mail at: rick515@delphi.com. *Note that an IRC Chat Session and Delphi online conference will be up and running live at the* **1994 tek.Conference.** *Schedules will be posted on Delphi's Scuba Forum and on the various Internet lists. Jack in.* (;—>).

And to really get Wired

check out this new technophile got-to-have publication from California, e-mail subscriptions@wired.com or call (800) So WIRED 1+(415) 904 0660 outside the US or snailmail: Wired @ 544 Second St, San Francisco, CA 94107-1427. Take your reel & line.

What were they breathing—

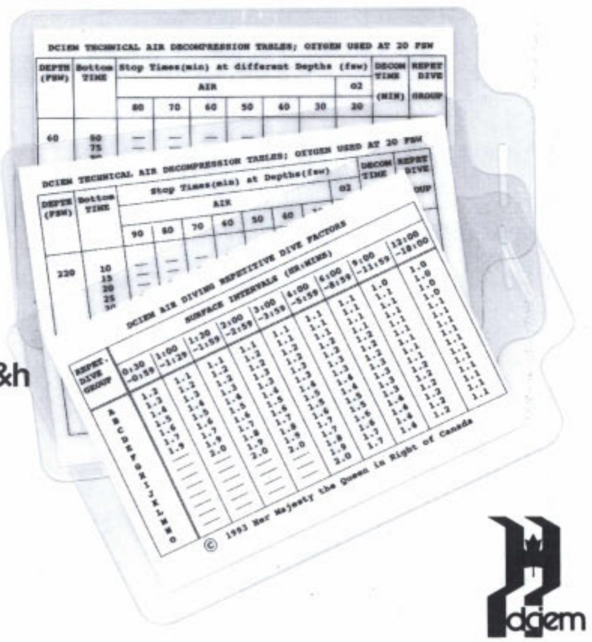
If your ready for a hoot call Dive Rite Mfrg. after hours @ 904.752.1087. What were those Florida boys breathing?



"Case was twenty-four. At twenty two, he'd been a cowboy, a rustler, one of the best in the sprawl. He'd operated on almost a permanent adrenaline high, a by product of youth and proficiency, jacked into a custom cyberspace deck that projected his embodied consciousness into the consensual hallucination that was the matrix."

William Gibson, Neuromancer

GEnie ScubaRT



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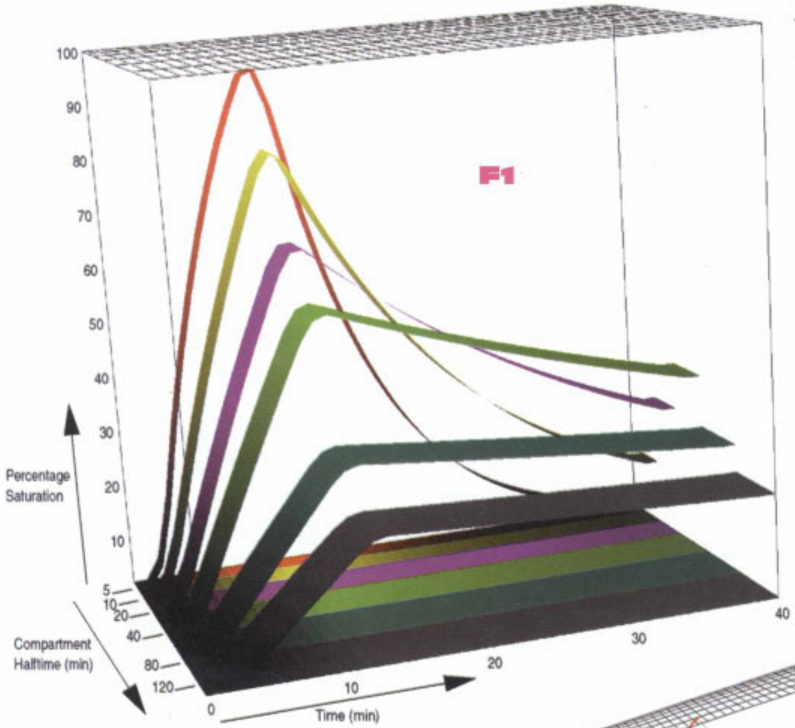


VISUALIZING DECOMPRESSIONS

by David Story

The day is near when the dive computer will be a staple in every diver's kit. Yet the most serious issue surrounding dive computers today is the question of user competence. Unfortunately, it appears that too few divers understand how their computers work, and blind reliance on computers has been documented in numerous case studies of decompression illness (DCI). Given the high level of literacy that most divers possess, it is unlikely that this is simply an inability to understand computer manuals. It is far more likely that a poor grasp of computational decompression theory is to blame. We need better tools to explain the theory behind dive computers.

I propose that interactive **decompression visualization**—a merger of decompression modeling, 3D animation, and scientific visualization —may be extremely effective in explaining decompression computation. This article is an introduction to the use of these tools.

A Single Dive

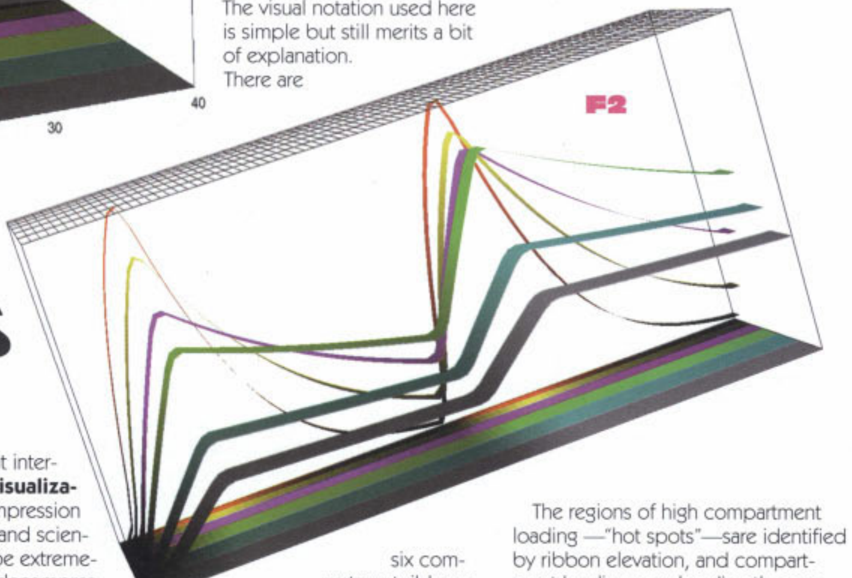
In most classes, instructors teach their students how to use a particular set of decompression tables rather than trying to explain underlying theory.

This is unfortunate because the theory is easy to explain when you use the right tools. To demonstrate, let's **visualize** an air dive to 130 fsw/39 msw with a bottom time of 10 minutes followed by a surface interval of 30 minutes. Figure F1 presents the results of modeling this dive with the Workman US Navy algorithm, using David Waller's DIVECOMP simulator.

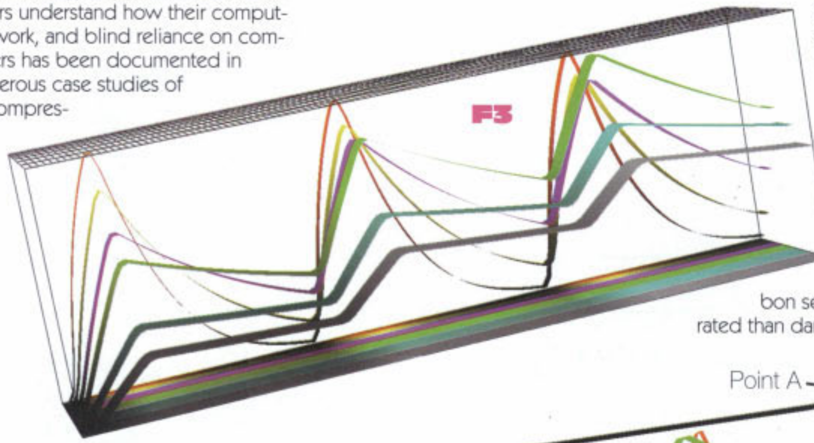
The visual notation used here is simple but still merits a bit of explanation. There are six compartment ribbons floating in space. These ribbons depict the continuous compartment loading for each of the six compartments. The widths of the ribbons are proportional to their half-times, which are noted along the lower left edge of the chart. Ribbon brightness and elevation are proportional to inert gas loading: brighter, higher ribbon segments are more saturated than darker, lower segments.

The vertical dimension is the percentage loading of the compartments, capped by a mesh "ceiling" indicating the "no-stop" limit. Time progresses from left to right. Finally, each tile in the floor reflects the coloring of the ribbon segment directly above it.

This single image presents every aspect of the algorithm in question, and every one of the data points in the simulation. **Visualization makes the important features obvious, even to the untrained eye.** You can immediately see how close the dive came to the algorithm's no-stop limits. Following the progression of compartment on and off-gassing over time provides an intuitive grasp of the differences between "slow" and "fast" compartments.



The regions of high compartment loading —"hot spots"—sare identified by ribbon elevation, and compartment loadings can be directly compared by their colored projections on the "floor" of the visualization. Most importantly the trends over the entire simulation can be seen in a single image rather than having to interpret reams of data. **Visualizations transform huge data sets into three-dimensional color images— exactly what the human eye and brain are designed to process.**



Repetitive Dives

Repetitive diving may be the most common contributing factor in DCI, yet few people really understand how algorithms take repetitive diving into account. **Visualization can provide a qualitative understanding of some important trends that appear only during repetitive diving.**

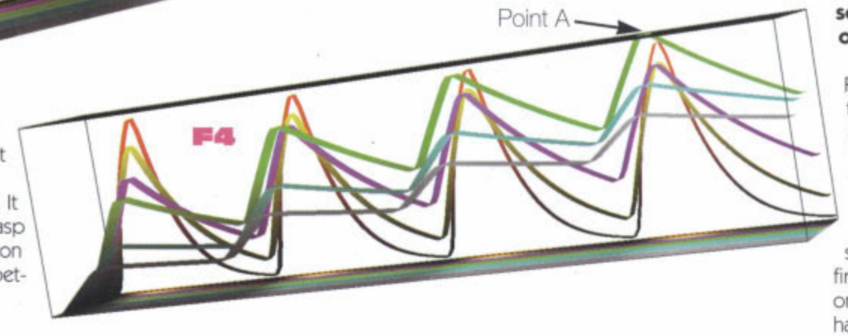


Figure F2 presents a visualization of the profile used in the previous example repeated twice in a row: a 130fsw/39msw dive for 10 minutes with a 30 minute surface interval followed by a repetitve dive to the same depth and time and another surface interval. Note that after the first surface interval (the middle of F2) only the fastest of the compartments has off-gassed completely. The slower compartments "ratchet" upwards during the second dive because they didn't completely off-gas during the surface interval. This can be seen by tracing one of the slower compartments in its upwards movement. This "ratcheting" effect graphically explains why no-stop limits are shorter on a repetitive dive.

Figure F3 presents the simulation of three identical 10 minute dives to 130fsw/39msw each followed by 30 minute surface intervals. In this case, the red five minute compartment ribbon nearly off-gasses during surface intervals, dropping to just a few percent. This is because the half hour surface interval is made up of six five minute half-times, and six is the number of half-times it takes a compartment to off-gas (almost) completely. That's why the five minute compartment controls each dive's no-stop duration, but can't control the dive series: it theoretically off-gasses too quickly to limit repetitive deep diving exposures.

Which compartment controls the dive sequence, and how does that compartment affects decompression time? Figure F4 presents four repetitions of the same dive viewed from a perspective that emphasizes the final dive in the series. At the end of the fourth dive (Point A), the simulated diver has clearly exceeded the no-stop limit of the 40 minute compartment (*The 40 minute ribbon hits the no-stop mesh at the top of the graph.*). It can also be seen from the slope of the ribbon that a decompression controlled by a slow compartment will necessarily be longer than one resulting from a fast compartment. By definition it takes more time to unload.

These brief examples illustrate the power of interactive 3D decompression visualization to explain decompression algorithms in an engaging and intuitive manner. Traditionally, understanding these computations required a grasp of applied mathematics, the ability to interpret very large data sets, and a basic understanding of applied physiology. Decompression visualization tools lessen the need to understand the mathematics and provide the means to intuit large data sets in a human-friendly way. **If a picture is worth a thousand words then a visualization is worth millions of numbers.**

David Story is an active diver and software engineer. The images used in this article were generated by Story using a custom graphic backend to Waller's numeric simulator running on an Silicon Graphics I^2. He can be contacted at R&D Divers, Suite 501, 1030 East El Camino Real, Sunnyvale, California 94087 fax: 415.969.2038 e-mail: story@sgi.com.

MORE INFORMATION

Friedhoff R, Benzon W, 1989. The Second Computer Revolution: Visualization; New York: W H Freeman & Company.
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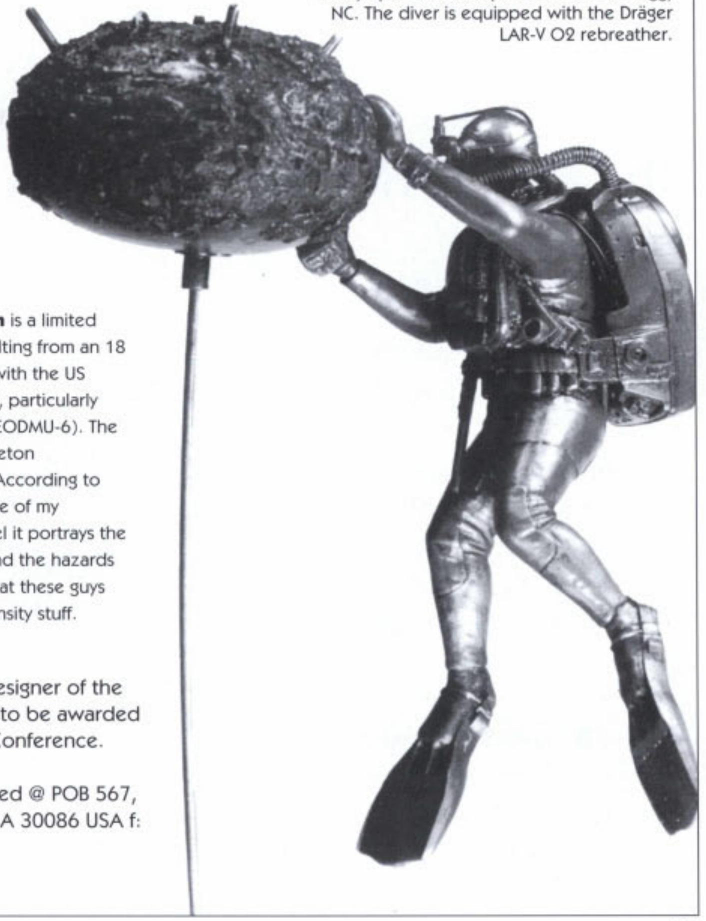
HEAVY METAL

No stranger to the C2 community, Augie Rodriquez is best known for cornflake breakfasts and the piéces de résistance; his intensely detailed sculptures of special operations divers. Hand cast. Hand finished. Cold bonded bronze. His work has been commissioned by the likes of NAVSPECWAR, US Special Forces (Army), Naval EOD, US Secret Service, US Marshals Service, The International Police Diver Symposium and the National Public Safety Divers championships. Definitely in the loop.

Combat Diver was based on a SEAL Team One operator with additional input provided by Special Forces personnel at Ft. Bragg, NC. The diver is equipped with the Dräger LAR-V O2 rebreather.



Naval EOD Technician is a limited edition sculpture resulting from an 18 month collaboration with the US Naval EOD community, particularly EOD Mobile Unit Six (EODMU-6). The diver is wearing a Carleton Technologies Mk-16. According to Rodriques, "EOD is one of my favorites because I feel it portrays the sense of weightless and the hazards of the environment that these guys operate in." High intensity stuff.

Rodriquez is the designer of the aquaCorps **tekkie** to be awarded F2F at the 94 **tek.**Conference.

He can be contacted @ POB 567,
Stone Mountain, GA 30086 USA f:
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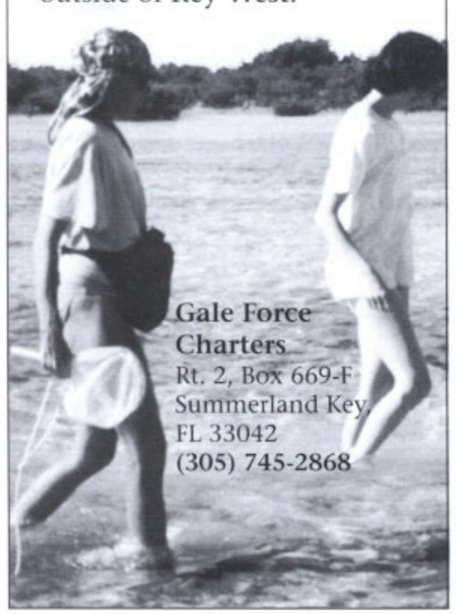
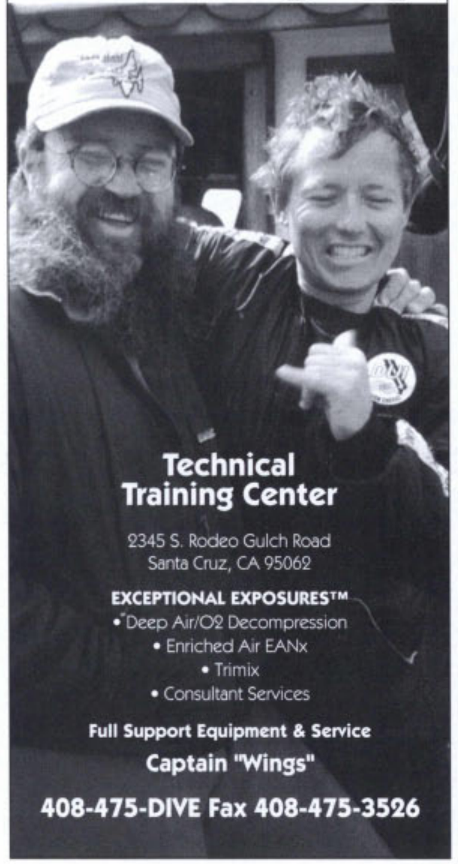




continued from page 28

mets can be worn without danger of CO_2 buildup as a result of the free flow capability of the system, and oxygen concentrations change automatically to provide optimum breathing mixtures at the diver's depth level. CO_2 is thoroughly scrubbed cryogenically. One model of the SS-1000 unit can be equipped with a closed loop water heating system which allows the diver to work in comfort regardless of water temperature.

In order to understand how the SSI cryogenic mixed gas system operates, one must first understand how certain gases behave at very low temperatures. The system is designed to handle oxygen and helium, which are used as a breathing mix, and the resulting carbon dioxide generated by the diver. These three gases each have different characteristics when reduced to cryogenic (very cold) temperatures. At sea level pressure, for example, carbon dioxide turns into a solid ("dry ice" or snow) at minus 110° F (minus 43.3° C). Oxygen turns into a liquid when its temperature is reduced to minus 298° F (minus 147.7° C). Helium does not liquefy until it reaches minus 450° F (almost absolute zero).

The SSI scuba can be considered a very efficient portable refrigerator. The "refrigeration" or low temperature of the unit is achieved by filling one of the cylinders with liquid nitrogen (LN_2), an inexpensive and readily available cryogenic fluid. The temperature of LN2 is approximately minus 320° F (minus 160° C) at sea level pressure. When the diver exhales a CO2/O2/He gas mixture into the scuba refrigerator, the carbon dioxide gas turns to "snow" when its temperature reaches minus 110° F, separates from the O_2/He gas stream and drops into the CO_2 trap. The oxygen gas turns into a liquid when its temperature reaches minus 298° F, separates from the helium gas stream and condenses back into the liquid oxygen supply tank. The helium is unaffected.

The amount of oxygen added to or deleted from the gas stream can be controlled by adjusting the pressure/temperature relationship in that part of the scuba. For example, if the gas stream is low in oxygen as it enters the oxygen supply tank, the necessary amount is added to the gas stream by evaporation from the liquid oxygen supply. The oxygen control process is automatically regulated—not by internal mechanisms—but by a relief valve mounted on the outside of the scuba. This valve controls the pressure of the LN_2 refrigerant bath by controlling the rate of escape of the refrigerant boil-off gas. The pressure of the LN_2 refrigerant bath, in turn, determines the partial pressure of the oxygen in the breathing gas stream. There are no valves, sensors or any other moving parts in the scuba. The process is one of interacting pressure/temperature relationships controlled by the adjustable external LN_2 refrigerant gas relief valve. Once the carbon dioxide has been frozen out and the proper oxygen concentration has been re-established by saturation with evaporating or condensing oxygen vapor, the gas stream is warmed up in a counter flow heat exchanger and routed back to the diver as pure adjusted inhale gas.

Because carbon dioxide removal and oxygen concentration control are accomplished by the process of passive temperature equilibrium, the reliability of the system is directly related to the thermal stability. Even if the oxygen control mechanism (refrigerant gas relief valve) became totally inoperative, oxygen partial pressures wouldn't reach toxic levels for at least an hour. It is this feature which makes cryogenic gas regeneration a *fail-safe* (sic) system for closed circuit mixed gas scuba.

The scuba is designed as a twin tank unit and appears similar to conventional air equipment. Each tank is a cryogenic dewar, or vacuum-insulated steel bottle. One dewar contains the counter flow heat exchanger and CO2 trap, which can store more than two pounds of carbon dioxide "snow" (the approximate amount that accumulates during six hours of heavy underwater work). The other dewar holds four liters of liquid nitrogen refrigerant and 30 standard cubic feet of oxygen in liquid form (oxygen is condensed internally to a liquid when loaded into the scuba). Fifteen standard cubic feet of helium is held in a cold coil in the same dewar at 3000 psi (occupying only one-fifth the volume required for non-cryogenic storage). The space between the cylinders is used to hold a canister containing three pounds of renewable chemical desiccant which prevents moisture from migrating through the internal cold lines of the scuba and protects against flooding. The space between the cylinders is used to hold a canister containing three pounds of renewable chemical desiccant which prevents moisture from migrating through the internal cold lines of the scuba and protects against flooding.

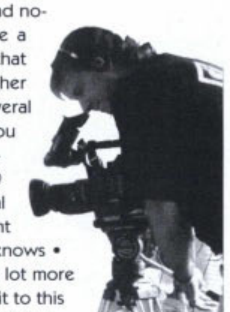
Rebreathers have been reborn. Other ocean technology companies are joining Sub-Marine Systems and designing deep diver breathing devices because they, like SSI, know that the days of complex large-scale underwater work sites and habitats are just around the corner. Humans will occupy the sea floor and perform constructive work however they will not be able to work efficiently until they have the small breathing units that provide the gas mixtures and heat required to support life safely and combat the chilling temperatures in the deep ocean. Once these units are built, the retrieval and development of the fantastic riches of the sea will begin—on a scale that is as unimaginable to us today.

A special thanks to Skin Diver Magazine, pioneers in diving publishing, for allowing us to reprint this article and to collector Dr. Samuel Miller, Anaheim, CA, for providing a copy of the original publication. Note that the article has been edited for space considerations. Cushman L, 1969JUN, Cryogenic rebreather, Skin Diver Magazine, p. 29-31, 85-87.

Update: Like many other C^2 prototypes, the SSI system never made it to market but went on to serve as the genesis for other systems. Based on some of the resulting spin-off technology, DiCharo went on to form Kinergentics which built commercial diving application products such as bell scrubbers and gas reclaim systems and is still in existence today. **According to some experts, cryogenic scrubbers represent a viable concept and remain on the forefront of rebreather technology.**

BEHIND.CLOSED CIRCUITS

aquaCorps has teamed up with underground film maker Chris Brown /Docent Films to produce a spirited one hour documentary exploring closed circuit technology • we have logged hundreds of hours acquiring rebreather footage and talking to C2 insiders from all over the planet about what is exactly going on • what we've found out is really amazing (to us anyway) there's a lot more going on than most people think• for example how would you like to repack a rebreather in space with the NASA Space Shuttle team? • be sure to watch out for that telescope • have coffee with the German Navy's Waffentauchengruppe command—an exclusive C2 interview discussing how they train their elite— the explosives ordinance and combat swimmer teams • test dive an Arawak Dolphin 7 commercial C2 bailout systems developed for really DEEP diving• get F2F with caver and engineer Bill Stone and team and dive the Cis-Lunar Mk-4 @ Ginnie• or chamber dive the Carmellan and Cis-Lunar rebreathers with Jim King of Deep Breathing Systems• watch Wes swim the Cis-Lunar Mk-1—a Skiles moment • get chatted up by British C2 entrepreneurs Stuart Clough and Peter Readey and walk off the beach with the new PRISM semi-closed rebreather perhaps the first system offered to sport divers• barter for one @ the Birmingham Dive Show • the Japanese may convert all their bubblers into rebreather divers if Grand Bleu has its way—maybe they'll come over here (;—>) • wanna buy a hot Russian military rebreather— they're for sale• let Dr. Maurice Cross give you the on-site @ Ft. Bovisand for more C2 testing and an entertaining chat, oh rubbish • meet the Carleton Technologies C2 management team and get a factory tour—objects dés art• @ visit with popular British cave and technical diver Rob Palmer @ home and underwater and discuss his plans to conduct an end user rebreather training program • have a frank discussion with Georges Arnoux, safety manager of Stolt Comex Seaways and chairman of the AODC Safety Committee in the North Sea • meet with Dr. Hubert Stieve, German Navy reservist and owner of a PADI 5-star facility on the Black Sea • lay line @ Silver Springs with map maker and no-mounter Eric Hutchinson with no bubbles • investigate a Carleton COBRA which are being used by police divers• chat up members of the British Sub Aqua Club and DIVER publisher Bernard Eaton who has been exhibiting rebreathers for several years • dive the USN's Mk-16 electronic mix rebreather you can't acquire one • yet • who's making a German semi-closed rebreather kit ? • discover C2 collectibles @ Florida's Man In The Sea Museum and the British Historical Diving Society • pick the brains of C2 developer and patent holder Tracy Robinette @ Divematics—what the shadow knows • go on site with the Naval Experimental Dive Unit they do a lot more than regulators • and for those of you who couldn't make it to this year's tek.Conference C2 sessions we'll be shooting all the good stuff we can and the best is yet to come• 94spring to be exact• stay in the loop **FOR MORE INFORMATION** Contact aquaCorps 1.800.365.2655• p: 305.294. 3540 • f: 305.293.0729



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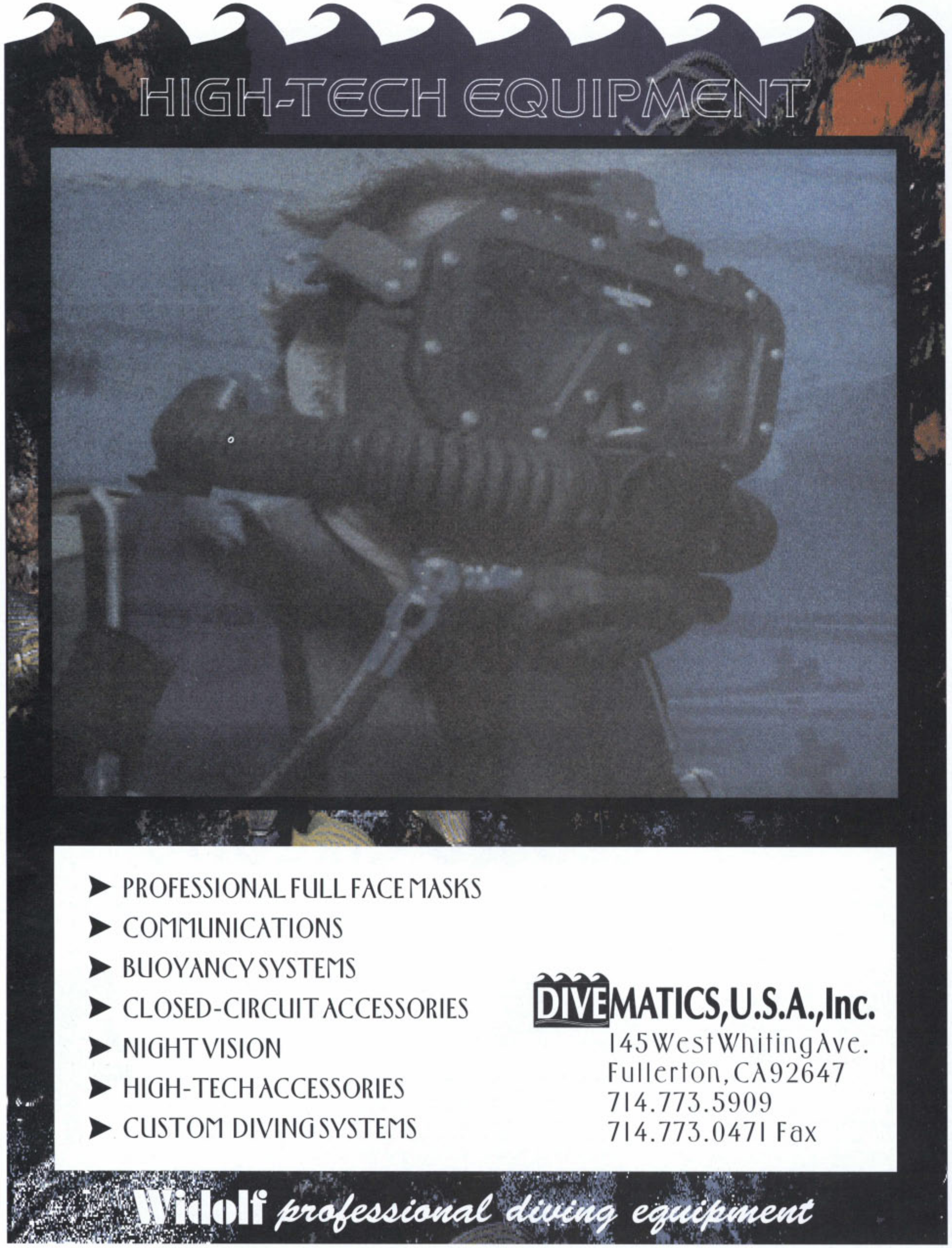
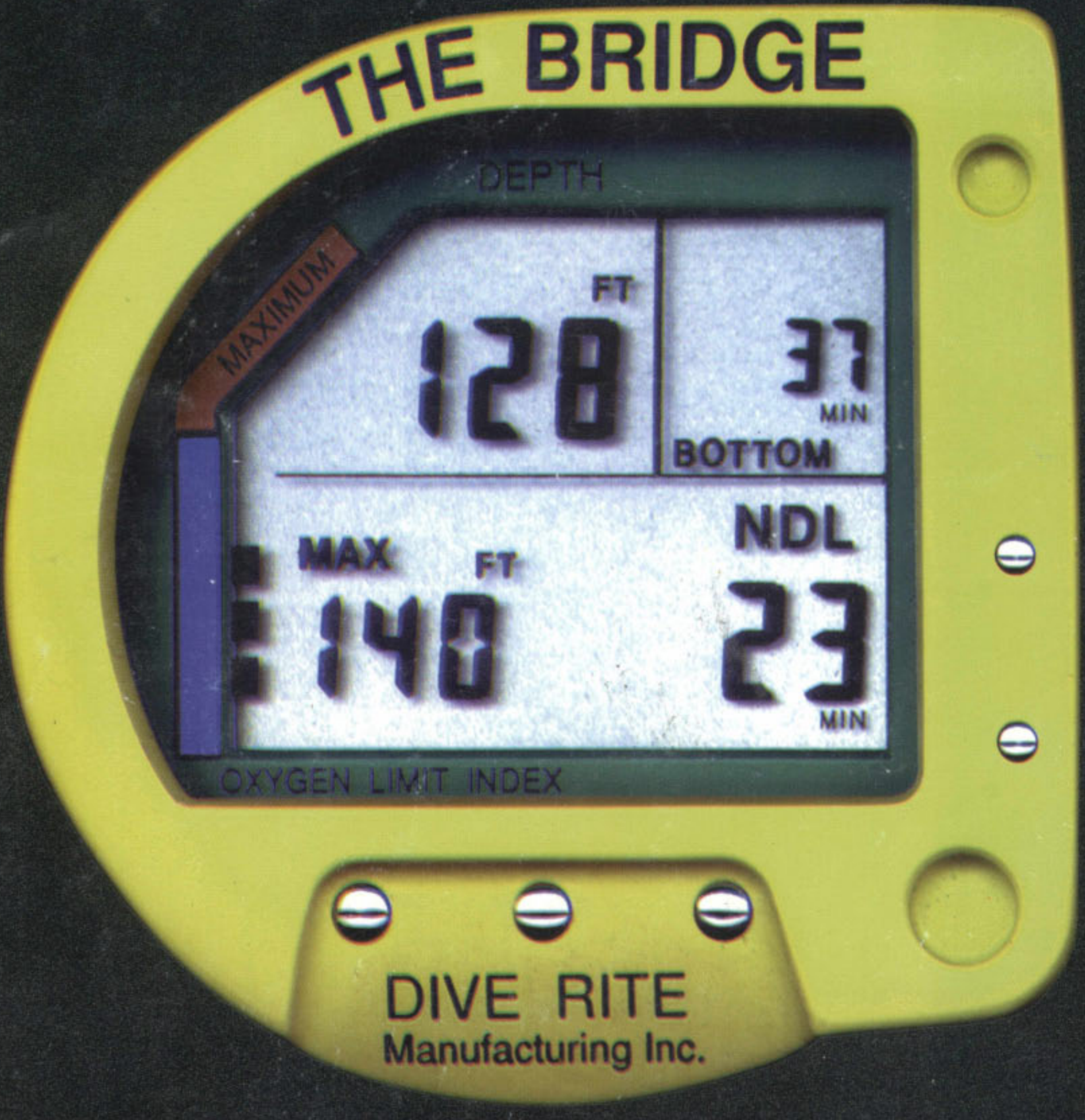


The New Nitrox Computer from Dive Rite



Enriched air nitrox (EAN) represents the new wave in diving safety and performance, much as the dive computer did in the eighties. The problem is that "air-based" dive computers simply aren't designed to manage enriched air decompression requirements. As a result, diving "nitrox" meant diving tables. Until now. **Created by Dive Rite Manufacturing Inc.**— the specialty diving people— **The Bridge** is a full function, high performance, variable-mix computer that's compatible with nitrox mixes. That means you can get the full performance of your diving mix, while improving your safety. In fact, **The Bridge** incorporates a lot of **safety and performance** features that we think you'll appreciate. Like a **oxygen tolerance algorithm** that tracks your exposure to increased partial pressures of oxygen and sounds an audible alarm when limits are reached. Full function **Bühlmann-based decompression monitoring** with stops to 90 fsw. **Dive logging. Dive profiling.** Time of day and date clock. Low battery warning. Not a mention a user friendly **PC interface and simulation software** that will let you record, analyze and plan your dives offline. **Dive the wave of the future.** Today. Call **1-904-752-1087** for the Dive Rite dealer near you. In the UK call **(0753) 841-686.** In Canada 905-985-0547. Or contact us at: 117 W. Washington St, Lake City, FL. 32055. Fax #: **(904) 755-0613.**

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